Project for the JINR University Center

Title

Properties of Pseudo-Scalar and Vector Mesons in Hadron and Heavy-Ion Collisions at Relativistic Energies

Description of the project

(i) The project is already under consideration. We have developed the appropriate formalism for describing pseudo-scalar mesons (e.g. D mesons) as bound states of two quarks within the Bethe-Salpeter approach together with Schwinger-Dyson equation. Now, for vector mesons (e.g. ρ mesons), the corresponding part is under consideration and ready to be implemented in the code. As in the case of pseudo-scalar mesons, the main mathematical tool here is the use of hyperspherical harmonics to decompose the spinor BS amplitude and to reduce the system of four-dimensional integral equations for the partial amplitudes to a system of one-dimensional integral equations. Another problem which needs more careful attention is the analytical continuation of the solutions of the truncated Schwinger-Dyson equation for heavy quarks.

First results are ready for publication in [1], where a mass spectrum of pseudo-scalar and vector mesons as a function of the quark masses for various combinations of quark is presented. However, as the meson mass increases, the method becomes less stable and special attention must be devoted to details of means of solving the corresponding equations. During the last year a significant effort have been paid for detailed investigation of [2-6] the analytical structure of quark propagators. For this sake a few independent numerical methods have been elaborated from which we undoubtedly found that the quark propagators posses poles in the complex Euclidean plane. In spite of, in general, an infinite number of poles, only few of them are located within the integration domain in the Bethe-Salpeter equation. Moreover, we argue that at relatively low values of the meson masses ($M \lesssim 1\ GeV$) all the singularities are outside the integration domain. As larger meson masses ($1\ GeV \lesssim M \lesssim 2\ GeV$), however, only few first (pairwise mutual complex conjugated) poles contribute to the solution. A careful analysis of such poles shows that they are integrable and the contribution is finite.

Another extremely interesting issue of such analysis of quark propagators is directly connected with the confinement in QCD. Namely, as well known, the quark propagators are related to the Schwinger functions. So, if the Schwinger functions were found to be non positive, this will necessarily require the confinement of the theory. In this context we also plan a thorough investigation of the properties of the Schwinger functions obtained from the Dyson-Scwhinger solution. Partially first results are already included in to the Ph.D. thesis of T. Hilger [4] anf diploma thesis of M. Viebach [3] and an article is ready for publication.

The approach will be extended also to all meson channels (from pseudo-scalar to vector, axial-vector and scalar) with the aim of providing a consistent description of the whole mass spectrum of mesons from an uniform point of view. The envisaged extensions are related to excitation spectrum and further meson properties to be deduced from the BS vertex functions.

Then we shall focus on in-medium effects by including an external field, which mimics an ambient nuclear medium. In particular, having solved the DSE and BSE equations at finite temperatures, we can investigate different modifications of D^+ and D^- mesons; also a study of the Mott transition at non-zero temperatures becomes feasible .

(ii) There are other methods of studies of D mesons embedded in nuclear matter. So, an alternative approach is based on the QCD sum rules. The intriguing point here is that terms like $m_c\langle\bar{q}q\rangle$ enter the operator product expansion of the "QCD side". For the light quark sector, the analog term is $m_q\langle\bar{q}q\rangle$. It is the mass difference of light quarks (m_q) and heavy quarks (m_c) which let us hope that D mesons are much more sensitive to changes of the chiral condensate $\langle\bar{q}q\rangle$ than light-quark mesons. The vision behind such ideas is to get a sensitive probe of the QCD ground state, since the chiral condensate as order parameter of the chiral symmetry breaking, is changed in dense nuclear matter compared to the vacuum. A manuscript reporting the calculations of Wilson coefficients of four quark condensates is presently finalised. Parts of the material (decomposition of condensate terms with tensor structure and the heavy-quark expansion) are published recently.

We expected results to sharpen the physics case of the CBM experiment which is presently designed as new large-scale detector installation at FAIR. The CBM experiment is motivated to investigate states of maximum baryon densities achievable in relativistic heavy-ion collisions. A general physical expectation is that here the in-medium modifications should show up most clearly. Among the issues studied is the understanding of the origin of "mass of hadrons". In dependence of various predictions, the colleagues are ready to supplement the detector by special components aimed at verifying these predictions as long as fundamental issues are addressed. In this respect, this part of our project will run over a medium term. Up to now, the direct experimental verification of medium modifications of hadrons, driven by a changed QCD ground state failed. As pointed out above, charm (or even bottom) probes may be more suitable. These are represented, at the energies of SIS300 at FAIR, by D mesons.

An extension to D^*, D_s and D_s^* is conceivable and will be attempted as soon the first steps are made successfully.

Acceptance criteria

The student assumes a basic knowledge of quantum field theory, programming skills, mastering the program Mapple, Origin.

The expected number of participants of the project

The number of the participants is 1-2 students from TU Dresden (FRG) and Belarus during 2015.