The theory groups of SUBATECH (Nantes) and of Catania University foresee an opening for a 3 year

Joint PhD position on "Heavy flavor production in small and large ultrarelativistic hadronic systems in the framework of the open quantum systems"

The context: The interpretation of the ultra-relativistic heavy ion collision (URHIC) data collected at the CERN and RHIC Collider is the center of interest of the high energy theory group at Subatech. It is believed that in such collisions, a new state of matter is achieved, the so-called quark-gluon plasma (QGP), where quarks and gluons usually confined in protons and neutrons are deconfined and free to propagate over large distances for a short lapse of time before cooling down and being converted in usual hadronic matter. Our both groups have developed in the recent years complementary expertise on heavy flavor production, under the form of open heavy flavor hadrons and of hidden charm or hidden beauty mesons, which is one of the most pertinent hard probes of the QGP, but also on the global modelling of the collisions, f.i. with the EPOS4 event generator on the Nantes side (https://klaus.pages.in2p3.fr/epos4/), what allows to study the soft physics in correlation with the HF production for large and small systems. On its side, Catania has vividly contributed to the consequences of the early stage of the URHIC, where transient electromagnetic fields and the interaction with the Glasma (dominated by strong gluon fields) could affect the HF production. They implemented a code simulating the early stage of the collisions based on the Glasma picture with realistic initial conditions for AA and pA collisions, as well as the evolution of HFs in the early stage and in the quark-gluon plasma by virtue of relativistic kinetic theory with the aim to determine phenomenologically the HF transport coefficients. In particular, they have developed also an hadronization scheme based on fragmentation plus coalescence that successfully predicted the enhancement of baryons over mesons in pp, pA and AA collisions wrt e^+e^-, e^-p collisions.

One of the most intriguing mechanisms associated with this area of physics is the process of (re)hadronization itself: how quarks emanating from the QGP will be dynamically converted into hadrons and which properties from the QGP will be imprinted on these hadrons. This question is crucial to be able to interpret the wealth of data measured by RHIC and LHC experiments. During the last years, we (among some researchers) have started to investigate the feasibility to deal with the hadronization of heavy quarks (c and b quarks) with their antiquark partner – into a so-called quarkonia – by adopting the viewpoint and concepts of the so-called "open quantum system" (see f.i. ref. [1-3]), which appears to be the correct dynamical framework for such situation. In particular, we were able to treat the somehow simpler case of bottomonia production at the large hadron collider (LHC) where only one beauty-antibeauty pair is considered, with promising perspectives. More recently, we have investigated the question of open-quantum system resorting to Linblad-like equations acting on the operator-density, simplified by resorting to semi-classical approximations [4]. This approach could be quite relevant in order to deal with the production of charmonia in AA collisions, a process which appears to be dominated by the recombination of exogenous pairs happening when the QGP cools down where semiclassical approximations may me relevant. These methods could also be applied to the recombination of one heavy quark with one light antiquark in order to develop a

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dynamical scheme complementing the instantaneous coalescence picture [5] which is the most used approach in the field.

The thesis project: The thesis project will aim to achieve theory developments in the field of heavy flavor production in URHIC collisions relying on the expertise of both groups, offering some flexibility depending on the candidate skills and motivations. A natural track would be to pursue the investigation of quarkonia production in URHIC resorting to the concepts and methods of open quantum systems (OQS). In particular, to focus the investigations on the topic of the dynamical Q-Qbar confinement that is restored during the cooling down of the QGP, that will be treated in the open-quantum system approach, taking into account the different stage of the evolution. Another opportunity would consist in extending the method to address the question of the hadronization of heavy quarks into open flavor mesons (and hadrons) in order to aim at a universal description,… Last but not least, combining the methods of OQS with the HF production at the initial stage of the collision may allow to gain in precision and in predictivity [6-7] and could also be interesting to compare the picture arising from a treatment based on OQS with that based on classical statistical simulations of the early stage as well as effective relativistic kinetic theories.

Apart from theoretical developments, some part of the PhD is expected to be devoted to phenomenological studies on the URHIC studied experimentally at RHIC and LHC colliders, in the most suitable numerical frameworks (EPOS4, relativistic effective kinetic theory, statistical classical simulations). This may encompass some extension to the case of collisions performed with large and small nuclei, as the resulting QGP properties depend on the system size.

This project offers the possibility to perform significant progresses in this highly debated topic of probing one of the most intriguing state of matter ever discovered by humanity. It will help the candidate to develop skills both in the field of theoretical nuclear and particle physics, as well as in statistical physics, while being balanced between theoretical developments and numerical investigations depending on the candidate's skills. It can thus be considered as a real springboard for the candidate's future career.

The candidate: We expect from the candidate a solid background in theoretical physics, especially of the different aspects of QCD as well as basic knowledge in numerical physics. Candidates with good knowledge of open quantum systems are encouraged to apply as well, even if they have a less extended background in QCD. In addition to disciplinary knowledge, the expected skills are: ability to carry out long and complex tasks by implementing control processes, spirit of initiative, imagination, curiosity, ability to work in a team.

It is important to notice that the candidate is expected to pass typically the same amount of time on both Catania and Nantes sites during the PhD.

The groups: The theory group of SUBATECH is composed of 14 permanent senior researchers (among them 9 oriented towards high energy physics), 2 postdocs and 6 PhD students. Further general information can be found on our website http://www-subatech.in2p3.fr. The theory group of Catania University is composed by 9 permanent senior researchers (among them 6 oriented towards high-energy physics), 3 young researchers, 3 postdocs and 4 PhD students; moreover, it has a direct collaboration with researcher at INFN.

The PhD advisors: The thesis will be supervised jointly by Prof P.- B. Gossiaux and Prof J. Aichelin for Nantes and by V. Greco and M. Ruggieri for Catania.

References:

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