PhD position in Theoretical Physics:
Dynamical thermalization in heavy-ion collisions

SUBATECH, Nantes, France
(starting fall 2018)

The context

After more than 30 years of heavy ion physics at different accelerators (SPS, RHIC, LHC), much has been learned about the possible formation of the new state of matter called **quark gluon plasma** (corresponding to the state of the universe after few microseconds), but there are still many open questions, in particular about the thermalization of the system. The dynamics is complicated, one has to consider different stages: There are primary scatterings (when projectile and target pass through each other), which define to a large extent the distribution of matter in phase space. Starting from these initial conditions, the partonic system will evolve in space and time until the system is sufficient dilute to “hadronize”.

Different models have different degrees of sophistication concerning the different stages (initial, evolution, hadronization). **EPOS** is a very sophisticated approach concerning the primary scatterings, then uses (assuming fast equilibration) hydrodynamical evolution, and hadronization via the simple Cooper-Frye procedure. **PHSD** has a sophisticated space-time evolution of the system, not imposing equilibration. From first studies, we see that the evolution in both models is completely different, leading in many cases to the same final results. In order to disentangle effects from the different stages, it looks very natural to **combine the two models**, what is precisely what we are planning to do.

We will take the **EPOS primary scattering approach to set the initial conditions**, using the EPOS string segments (see below) to make the link to PHSD, and then follow the evolution based of the **PHSD dynamics**. Comparing in this way (assumed) equilibrium evolution with a non-equilibrium approach, will provide completely new and needed information about what we can conclude from today's experimental data about the existence of a thermalized plasma.

The project

EPOS is a very sophisticated approach concerning the primary scatterings. It is a multiple scattering approach (per nucleon-nucleon collision). Each elementary scattering process is described by Pomeron exchange, a Pomeron being realized as parton ladder (a linear parton evolution), whose final state is an essentially longitudinal color field. The dynamics of these flux tubes is described by relativistic strings. In elementary collisions, the string breaking by quark-antiquark production leads to hadron formation from the individual string segments. A very important aspect of EPOS is the treatment of high parton density effects, representing nonlinear parton evolutions, which are accounted for by implementing a dynamical saturation scale, which depends for each Pomeron on its energy, but also the environment (neighboring Pomerons). The approach is compatible with the current understanding of parton saturation.

In nucleus- nucleus collisions or high multiplicity proton-proton scattering, the density of flux tubes is large, they must interact. To account for this, we employ a so-called core-corona separation of string segments, at a given proper time. Those string segments which are slow and/or far from the surface constitute the core, the others (corona) escape. The core is assumed to quickly constitute locally thermalized matter and then evolves as a viscous fluid. The fluctuating flux tube positions allow us to treat the fluid dynamical evolution event by event accounting for the fluctuating spatial structure of single events. The full 3+1d fluid dynamical simulation is performed including a parametrization of the equation of state from lattice QCD.

PHSD (Parton-Hadron-String Dynamics) is a microscopic covariant dynamical model for strongly interacting systems formulated on the basis of Kadanoff-Baym equations. The approach consistently describes the full evolution of a relativistic heavy-ion collision from the initial hard scatterings and string formation through the dynamical deconfinement phase transition to the strongly-interacting quark-gluon plasma (sQGP) as well as hadronization and the subsequent interactions in the expanding hadronic phase. The transport theoretical description of quarks and gluons in the PHSD is based on the Dynamical Quasi-Particle Model (DQPM) for partons that is constructed to reproduce lattice QCD for QGP thermodynamics via effective propagators for quarks and gluons.

In the beginning of relativistic heavy-ion collisions color-neutral strings (described by the LUND model are produced in highly energetic scatterings of nucleons from the impinging nuclei. These strings are dissolved into 'pre-hadrons'. If the local energy density is larger than the critical value for the phase transition, which is taken to be ∼ 0.5 GeV/fm3 , the pre-hadrons melt into (colored) effective quarks and antiquarks in their self-generated repulsive mean-field as defined by the DQPM.

Both **EPOS and PHSD are among the most visible models** in the field. **EPOS** has been very successfully applied to analyze heavy ion collisions at the RHIC collider and more recently mainly to analyze flow effects in small systems. The model is also very much used by major LHC experiments and as interaction model for air shower simulations. Main publications {in curly brackets the citations from Google}: Physical Review C 74 (2006) 044902 {554}, Physical Review C 92 (2015) 034906 {441}, Physics Reports 350 (2001) 93-289 {416}, J.Phys. G35 (2008) 054001 {387}. EPOS has also been presented in a **plenary talk at Quark Matter 2014** (the most important conference in our field) and at Strange Quark Matter 2014 and 2017 (the second most important conference in our field). **PHSD** has been mainly applied to analyze heavy ion collisions from SIS to LHC energies. Main publications {in curly brackets the citations from Google}: Physical Review C 69 (2004), 054907 {239}, Physical Review C 83 (2011) 054911 {223}, Nuclear Physics A 831 (2009), 215-242 {194}, Physics Reports 510 (2012), 119-200 {158}. PHSD has also been presented in a **plenary talk at Quark Matter 2014** (the most important conference in our field) and at Strange Quark Matter 2016 and 2017 (the second most important conference in our field).

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