

MIAPP Programme 2018

Heavy Ion

Monday 27 August 2018 - Friday 21 September 2018

MIAPP



Book of Abstracts

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Week 1 / 21

Dynamical core-corona initialization in hydro models

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One of the important findings in small colliding systems at the LHC energies is that yields of (multi-)strange hadrons enhance more rapidly than those of charged pions as functions of multiplicity. To interpret this, we develop a dynamical initialization model with core-corona picture in hydrodynamic models. We generate the initial partons using some event generator. We put them in the source terms of relativistic hydrodynamic equations to generate the QGP fluids. Some of the initial partons with high pT or those isolated from the others are able to survive after dynamical initialization and form a hadronic string to decay into hadrons. Thus, in this framework, final hadrons come from either chemically equilibrated fluids (core) or string fragmentation (corona). By using this model, we reasonably reproduce the yield ratio of (multi-)strange hadrons to charged pions as a function of multiplicity observed by the ALICE Collaboration. We claim that hydrodynamic analysis of experimental data requires this kind of core-corona picture for better understanding of the whole reaction process of high-energy nuclear collisions.

Week 1 / 28

Pre-equilibrium stages with QCD kinetic theory

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The produced matter in the high energy nuclear collisions reinteracts and form a plasma which ultimately equilibrates and exhibits collective hydrodynamic flow.
The connection between the early gluon production in classical field simulations and hydrodynamic expansion at later times is given by the QCD kinetic theory.
I will discuss the recent progress on smooth matching between these three stages, including the hydrodynamization and chemical equilibration of Quark-Gluon Plasma.

Week 1 / 43

Some results and challenges for hydro modelling at RHIC BES

Iurii Karpenko¹¹ *SUBATECH Nantes***Corresponding Author(s):** yu.karpenko@gmail.com

In this talk I overview the results of our studies of heavy ion collisions at RHIC BES energies in the framework of a viscous hydro + cascade model, vHLL+UrQMD, focusing on the following phenomena:

- Lambda polarization - from RHIC BES to LHC energies
- Femtoscopic observables at RHIC BES

And discuss challenges for hydrodynamic modelling at the lower collision energies (RHIC BES, FAIR, NICA energies)

Week 1 / 32

A new relativistic viscous hydrodynamics code for high-energy heavy-ion collisions

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A relativistic viscous hydrodynamic model plays an important role in the quantitative understanding of the QGP bulk property. In spite of the success of hydrodynamic models in high-energy heavy-ion collisions, there are still several issues under discussion. In particular, we emphasize that a numerical algorithm for solving the relativistic hydrodynamic equation is one of the important ingredients in developing the hydrodynamic models. Recent high statistical experimental data at RHIC and the LHC imposed a more rigorous numerical treatment on the hydrodynamical models.

Here we construct a new relativistic viscous hydrodynamics code optimized in the Milne coordinates. We split the conservation equations into an ideal part and a viscous part, using the Strang spitting method. In the code a Riemann solver based on the two-shock approximation is utilized for the ideal part and the Piecewise Exact Solution (PES) method is applied for the viscous part. We check the validity of our numerical calculations by comparing analytical solutions, the viscous Bjorken's flow and the Israel–Stewart theory in Gubser flow regime.

Using our developed new relativistic viscous hydrodynamics code, we investigate the temperature dependence of shear and bulk viscosities from comparison with the ALICE data; single particle spectra and collective flows at Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV collisions at the Large Hadron Collider. We find that from the comprehensive analyses of centrality dependence of single particle spectra and collective flows, we can extract the detailed information of the QGP bulk property, without being smeared by the final state interactions.

Week 1 / 18

Convergence of the Method of moments and Attractor Solutions of the Boltzmann Equation

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Relativistic hydrodynamics has played a key role in our understanding of the novel properties of quark-gluon plasma. However, the validity of hydrodynamical models in describing the extreme

conditions produced in heavy ion collisions has still not been properly justified theoretically. Even more, the gradient expansion, commonly used to derive hydrodynamics from microscopic theory, has been recently shown to diverge for conformal fluids or relativistic gases undergoing Bjorken flow [1,2], putting under question the definition of hydrodynamics itself.

In this contribution, another approach to derive relativistic hydrodynamics from the Boltzmann equation is discussed: the method of moments [3]. We investigate the convergence of this approximation scheme under Bjorken flow and Gubser flow and show that, in contrast to the gradient expansion, the method of moments appears to be convergent. Finally, we discuss whether there is an attractor for solutions of the full Boltzmann equation, both in the relaxation time approximation and for a collision term including elastic 2-to-2 collisions.

[1] M. P. Heller and M. Spalinski, "Hydrodynamics Beyond the Gradient Expansion: Resurgence and Resummation," Phys. Rev. Lett. 115, no. 7, 072501 (2015).

G. S. Denicol and J. Noronha, "Analytical attractor and the divergence of the slow-roll expansion in relativistic hydrodynamics," Phys.Rev. D97 (2018) no.5, 056021.

G. S. Denicol, H. Niemi, E. Molnar, and D. H. Rischke, "Derivation of transient relativistic fluid dynamics from the Boltzmann equation," Phys. Rev. D 85, 114047 (2012).

Week 1 / 1

Hydrodynamic flow in small systems?

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The "unreasonable effectiveness" of relativistic fluid dynamics in describing high energy heavy-ion and even proton-proton collisions will be demonstrated and discussed. Several recent ideas of optimizing relativistic fluid dynamics for the specific challenges posed by such collisions will be presented, and some thoughts will be offered why the framework works better than originally expected. I will also address the unresolved question where exactly hydrodynamics breaks down, and why.

Week 1 / 4

Connecting rapidity-dependent hydrodynamic flow to initial conditions

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Relativistic viscous hydrodynamics consists of a set of complicated nonlinear differential equations. Nevertheless, it is possible to find simple relations between particular aspects of the initial conditions and final observables in hydrodynamic simulations of relativistic heavy ion collisions. The canonical example is the event-by-event proportionality between elliptic flow and initial eccentricity. These relations provide a powerful tool for understanding the behavior of the collision system, separating properties of the initial stages and of the QGP medium, and directly accessing such properties from experimental data.

However, these relations have only been developed in a 2-dimensional context, relating initial and final quantities that have been averaged over rapidity. In this talk I will discuss extending to rapidity dependent relations – how to define rapidity-dependent eccentricities and related quantities, to what extent rapidity-dependent flow can be estimated from these eccentricities, and how to extend to non-local relations. These relations will be useful for analyzing various rapidity-dependent correlation observables and using them to determine properties of the collision system, in a similar way to what was done in the rapidity-independent case.

Week 1 / 5

Longitudinal structure, correlated gluonic hot spots and hadronic dynamics

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Longitudinal fluctuations originating from strings in the initial state of high-energy heavy ion collisions are investigated within an AMPT+CLVIs relativistic fluid dynamics calculation. The results are compared to CMS and STAR data on the decorrelation of event planes.

The sub-structure of protons is crucial to understand collective effects in small systems. In this work, correlations between gluonic hot spots are investigated and in particular the effect of the correlations on flow correlation observables. First, this is evaluated in coordinate space and first results for the corresponding final state momentum space structures after a hydrodynamic evolution are also shown.

A new hadron transport approach (SMASH) is introduced and validated against bulk observables at SIS energies. The hadron gas viscosity as a function of temperature and baryon chemical potential has been calculated within this approach, highlighting the influence of resonance lifetimes on the relaxation dynamics of the system. The effect of hadronic rescattering on flow and correlation observables at high energies is assessed. In addition, this approach is applied to study the initial collisions at intermediate beam energies to understand the baryon stopping dynamics that is highly relevant for the beam energy scan program at RHIC and future FAIR.

Since heavy ion collisions are complex and the modelling contains many uncertainties, we have applied deep learning techniques to assess sensitivities in the transverse momentum - azimuthal angle plane of final state particles to the equation of state. I will report on a proof-of-principle study employing fluid dynamics for the dynamical evolution of the system.

Week 1 / 25

Centrality fluctuation in heavy-ion collisions

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Centrality fluctuations (CF) is one of the main uncertainties for interpreting the centrality dependence of many experimental observables. The influence of CF for any bulk observable can be studied from the multi-particle cumulants of its event by event distribution. Using a Glauber-based independent source model, we study the influence of CF on several distributions of multiplicity N and eccentricities e_n : $p(N)$, $p(e_n, e_m)$, $p(N, e_n)$. In ultra-central collisions, where distribution of particle production sources is strongly distorted, we find these cumulants exhibit rich sign-change patterns, due to observable-dependent non-Gaussianity in the underlying distributions. The details of sign-change pattern change with the size of the collision systems. Simultaneous comparison on these different types cumulants between model prediction and experimental data can be used to constrain the CF and particle production mechanism in heavy-ion collisions. Since the concept of centrality and CF are expected to fluctuate in the longitudinal direction within a single event, we propose to use pseudorapidity-separated subevent cumulant method to explore the nature of intra-event fluctuations of centrality and collective dynamics. The subevent method has the potential

to separate different mechanisms for multiplicity and flow fluctuations happening at different time scales. The forward detector upgrades at RHIC and LHC will greatly enhance such studies in the future.

Week 1 / 38

Electromagnetic radiation and hydrodynamic modelling of heavy-ion collisions

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Most of the information we have about the phases modelled by hydrodynamics in relativistic nuclear collisions comes from the analyses of hadronic collectivity. However, electromagnetic radiation (real and virtual photons) can be both penetrating and soft, and as such opens a unique window to the space-time regions that are opaque to hadrons. In this talk, we will review how measurements of photons and leptons can inform our knowledge of the dynamics of relativistic hadronic reactions at RHIC, LHC, and BES energies, as well as our understanding of the transport coefficients of strongly interacting matter.

Week 2 / 22

Alpha clusters and beam polarization effects in the initial state

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We discuss the imprints of alpha clusterization in light nuclei on the eccentricities in the initial stage in the light-heavy collisions. We also explore possible effects of beam polarization in d-A collisions, where the orientation of d correlates to activity of the reaction and ellipticity.

Week 2 / 19

Ultracentral heavy-ion collisions as a probe of nuclear structure

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In recent years heavy-ion collisions have noted that a preference for both a deformed proton and deformed nuclei are seen in comparing flow observables to relativistic viscous hydrodynamic calculations. Thus far, all deformations of nuclei have only considered the ground state of the nucleus. In the case of XeXe collisions, it was found that the deformed Xenon nucleus increase elliptical flow in very central collisions $\sim 0-5\%$. In PbPb collisions a similar discrepancy was also found where triangular flow is consistently under-predicted by hydrodynamics calculations. In this talk, the first excited state of Pb nuclei that has a pear shape is considered, which has the effect of increasing triangular flow in central PbPb collisions, which aids in understanding the v_3 puzzle in ultracentral PbPb collisions at the LHC.

Week 2 / 6

Determination of Quark-Gluon-Plasma properties via Bayesian analysis

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A primary goal of heavy-ion physics is the measurement of the fundamental properties of the quark-gluon plasma (QGP), notably its transport coefficients and initial state properties. Since these properties are not directly measurable, one relies on a comparison of experimental data to computational models of the time-evolution of the collision to connect measured observables to the properties of the transient QGP state. These model-to-data comparisons are non-trivial due to the large number of model parameters and the non-factorizing sensitivity of measured observables to multiple parameters.

Over the last few years the Duke QCD group has developed techniques based on Bayesian statistics that allow for the simultaneous calibration of a large number of model parameters and the precision extraction of QGP properties including their quantified uncertainties. The computational model used is based on the Trento initial condition model, viscous relativistic hydrodynamics and a microscopic hadronic transport to describe the off-equilibrium late stage hadronic evolution. The analysis starts by selecting a set of salient model parameters - including physical properties such as temperature and/or momentum dependent transport coefficients - then evaluates the event-by-event heavy-ion collision model at a small set of points in the multidimensional parameter space, varying all parameters simultaneously. Gaussian process emulators are used to non-parametrically interpolate the parameter space, providing fast predictions at any point in parameter space with quantitative uncertainty. Finally, the parameter space is systematically explored using a Markov chain Monte Carlo (MCMC) to obtain rigorous constraints on all parameters simultaneously, including all correlations among the parameters.

In this talk I will review the basic components of the Bayesian analysis and discuss recent progress in the determination of QGP initial conditions and transport coefficients with special emphasis on flow observables and the specific shear and bulk viscosity of the QGP.

Week 2 / 35

Polarization in relativistic fluids

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The observation of a finite global polarization in agreement with theoretical predictions has opened a new dimension in relativistic heavy ion physics as well as in relativistic hydrodynamics, with several intriguing connections to chiral and electromagnetic effects. Very recent experimental observations seem to challenge the hydrodynamic predictions. In this talk, the status of the theory of polarization in relativistic fluids is reviewed and possible developments in the field are discussed.

Week 2 / 10

One particle distribution function and shear viscosity in magnetic field: a relaxation time approach

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We calculate the δf correction to the one particle distribution function in presence of magnetic field and non-zero shear viscosity within the relaxation time approximation. The δf correction is found to be electric charge dependent. Subsequently, we also calculate one longitudinal and four transverse shear viscous coefficients as a function of dimensionless Hall parameter χ_H in presence of the magnetic field. Calculation of invariant yield of π^- in a simple Bjorken expansion in longitudinal direction along with a realistic transverse expansion of fluid shows that both p_T spectra and elliptic flow is altered due to the δf correction for a realistic values of the magnetic field and relaxation time.

Week 2 / 30

Collectivity of heavy flavor quarks in small collisions system

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Recent years, evidence for collective effects has been revealed in small collision systems when looking at events releasing large number of particles. The experimental observations lead to a debate of the formation of strongly coupled Quark-Gluon Plasma in those small collision systems. Azimuthal anisotropy coefficient (v_n) of heavy-flavor quarks can shed light on their coupling strength to the hypothesized hydrodynamic medium at a significantly reduces size, and impose further constrains on different interpretations related to the origin of the observed collectivity. In this talk, I will present a review of the most recent experimental results of heavy-flavor quark v_n in small collision systems, and discuss their implications, as well as new opportunities and challenges that arise from the results.

Week 2 / 27

Fluctuations and long time tails in fluid dynamics

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We study the role of fluctuations in relativistic fluid dynamics. We consider two issues, long-time tails in current-current correlation functions, and simulations of baryon diffusion in the vicinity of a critical point.

Week 3 / 2

Open heavy-flavour: present measurements and future directions

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Strongly interacting matter at high temperatures and large densities can be created and carefully studied under laboratory conditions in high-energy collisions of heavy atomic nuclei. Especially, heavy quarks (charm and beauty) provide particular good probes to study the QCD plasma and its evolution since they are predominantly produced in initial hard partonic scattering processes in the early stages of the collision.

Both the Large Hadron Collider (LHC) at CERN and the Relativistic Heavy Ion Collider (RHIC) at BNL provide heavy-ion collisions at unprecedented energy densities. The measurement of open heavy-flavour production in such collisions allows the study of the dynamical properties of the plasma phase through the energy loss of heavy quarks.

In this contribution, an overview will be given of current open heavy-flavour measurements from RHIC and the LHC as well as future directions and new observables.

Week 3 / 3

Charmed hadrons production with RRM

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We generalize the resonance recombination model (RRM) for the production of mesons to the case of baryons and demonstrate the “equilibrium mapping” admitted by RRM thanks to energy conservation. We then use the RRM to calculate the production of charmed hadrons in relativistic heavy-ion collisions, with charm quark spectra simulated from relativistic Langevin dynamics. We emphasize the role of resonant interactions both in the diffusion of heavy quark in the Quark-Gluon Plasma as well as in the heavy quark hadronization.

Week 3 / 33

Nuclear PDF and heavy flavor production

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I will discuss the LHC heavy flavor data in pA collisions to constrain the gluon density at low x in nuclei, where no other data exist. Our results show strong gluon shadowing at low x compared to proton PDF and significant reduction of the current (underestimated) nPDF errors. Its implications for the heavy-ion physics will also be discussed.

Week 3 / 15

Quarkonium production in p-A collisions: a tool for estimating non-QGP effects in AA,?

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Results on quarkonium production in p-Pb collisions from LHC run-1 and run-2 have now reached a considerable accuracy and represent, together with RHIC findings, an important tool for the study of cold nuclear matter effects. While for strongly bound states those effects are probably dominated by nuclear shadowing, excited quarkonium states have been shown to be affected by additional mechanisms, likely related to final state dissociation. As the size of these effects is not negligible, their contribution can be significant and in principle affect our interpretation of A-A results.

It remains to be seen if the information gained via the study of p-A collisions can be effectively used to extract information on the contribution of non-QGP effects to quarkonium production in A-A interactions.

In this contribution, the main results obtained at the LHC from the study of p-Pb collisions will be critically reviewed and possible extrapolations of the presently available data to the conditions of nucleus-nucleus collisions will be discussed. In this way, it could be possible to provide clues to some of the present issues in the field, as the evidence for direct suppression of the bottomonium 1^{--} ground state ($\Upsilon(1S)$) in A-A collisions, as well as more precise insights on the size of the recombination mechanisms for J/ψ production at low p_T .

Week 3 / 14

Heavy Flavor Azimuthal Correlations in Cold Nuclear Matter

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It has been proposed that the azimuthal distributions of heavy flavor quark-antiquark pairs may be modified in the medium of a heavy-ion collision. This assumption is tested through next-to-leading order (NLO) calculations of the azimuthal distribution, $d\sigma/d\phi$, including transverse momentum broadening, employing $\langle k_T^2 \rangle$ and fragmentation in exclusive $Q\bar{Q}$ pair production. The differences between NLO calculations and heavy $Q\bar{Q}$ pair production in event generators are also discussed.

First, single inclusive p_T distributions calculated with the exclusive HVQMNR code are compared to those calculated in the fixed-order next-to-leading logarithm approach. Next the azimuthal distributions are calculated and sensitivities to $\langle k_T^2 \rangle$, p_T cut, and rapidity are studied at $\sqrt{s} = 7$ TeV. Finally, calculations are compared to $Q\bar{Q}$ data in elementary $p + p$ and $p + \bar{p}$ collisions at $\sqrt{s} = 7$ TeV and

1.96 TeV as well as to the nuclear modification factor $R_{p\text{Pb}}(p_T)$ in p +Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV measured by ALICE. While these studies were done for $p + p$, $p + \bar{p}$ and p +Pb collisions, understanding azimuthal angle correlations between heavy quarks in these smaller, colder systems is important for their interpretation in heavy-ion collisions.

The low p_T ($p_T < 10$ GeV) azimuthal distributions are very sensitive to the k_T broadening and rather insensitive to the fragmentation function. The NLO contributions can result in an enhancement at $\phi \sim 0$ absent any other effects. Agreement with the data was found to be good.

The NLO calculations, assuming collinear factorization and introducing k_T broadening, result in significant modifications of the azimuthal distribution at low p_T which must be taken into account in calculations of these distributions in heavy-ion collisions.

Week 3 / 31

Potential of LHCb in heavy-ion collisions

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LHCb is one of the four large experiments at the LHC. It has taken ion-ion collisions and dedicated fixed-target data samples for the first time in 2015. In this contribution, we will discuss not yet exploited experimental possibilities for this forward acceptance detector both in the correlation as well as in the heavy-flavour sector. The goal is to trigger an open discussion on new ideas that are not exclusively directed towards LHCb.

Week 3 / 44

AFTER@LHC

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Perspectives with AFTER@LHC

Week 3 / 36

Loop functions in thermal QCD

Antonio Vairo¹

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We present recent computations of loop functions in thermal QCD like the Polyakov loop, correlators of Polyakov loops and Wilson lines, and the cyclic Wilson loop. We discuss divergences and how to renormalize them. Finally we compare with lattice data.

Week 4 / 7

Quarkonium production in the Statistical Hadronization Model

Anton Andronic¹¹ *Muenster University***Corresponding Author(s):** andronic@uni-muenster.de

Assuming full screening of quarkonia in QGP as well as full thermalization of charm quarks in QGP, quarkonium production in the Statistical Hadronization Model occurs at chemical freeze-out (which, for high energies, likely coincides with the QCD phase boundary). The model describes very well the LHC J/psi data on centrality, transverse momentum and rapidity dependence and gives definite predictions for psi(2S) production.

Whether the same generation mechanism applies for the bottomonium is not inconroversial, but remains a tantalizing possibility, which will be presented as well.

Week 4 / 9

From Heavy-Flavor Transport to Microscopic Properties of the Quark-Gluon Plasma

Ralf Rapp¹¹ *Texas A&M University***Corresponding Author(s):** rapp@comp.tamu.edu

Heavy-flavor particles are believed to be versatile probes of the medium produced in high-energy nuclear collisions. Their masses provide a large scale which implies several benefits in the theoretical and phenomenological analysis of their vacuum and in-medium properties. We discuss a selfconsistent many-body approach that allows for a comprehensive description of both bound and scattering states, encompassing quarkonia and the diffusion of open heavy flavor in the quark-gluon plasma and through hadronization. We address the problem of extracting the underlying potential interaction using constraints from lattice QCD results on the heavy-quark free energy and quarkonium correlators. We then examine in how far the properties of the heavy-quark interactions can be utilized to understand the bulk, spectral and transport properties of the quark-gluon plasma, to do justice to the original idea of using the heavy-quark systems as a probe of the medium.

Week 4 / 13

In-medium properties of heavy flavor mesons from lattice QCD

Peter Petreczky¹¹ *BNL***Corresponding Author(s):** petreczk@bnl.gov

I will review recent progress in studying the in-medium properties of open heavy flavor mesons and quarkonia from lattice QCD. I will report on recent results on in-medium spectral functions for bottomonia and charmonia from non-relativistic QCD (NRQCD). Discuss new results on the determination of the complex heavy quark potential

on the lattice. Furthermore, I will show results on spatial correlation functions of heavy flavor mesons.

Week 4 / 26

In-medium effects in the spectrum of baryons

Gert Aarts^{None} ; Chris Allton¹ ; Davide De Boni^{None} ; Jonas Glesaaen^{None} ; Simon Hands^{None} ; Benjamin Jäger^{None} ; Chrisanthi Praki^{None}

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Baryons with various strange content are studied across the deconfinement transition using our $N_f=2+1$ flavour anisotropic FASTSUM lattices. Below T_c we find that the positive-parity states are largely temperature independent, whereas the negative-parity hadron masses decrease as T_c is approached. Near, and above T_c , the parity partners' masses converge, with parity doubling being closest for hadrons with the least strange quark content, a result expected from chiral symmetry arguments

Week 4 / 17

The static hard-loop gluon propagator to all orders in anisotropy

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We calculate the (semi-)static hard-loop self-energy and propagator using the Keldysh formalism in a momentum-space anisotropic quark-gluon plasma. The static retarded, advanced, and Feynman (symmetric) self-energies and propagators are calculated to all orders in the momentum-space anisotropy parameter ξ . For the retarded and advanced self-energies/propagators, we present a concise derivation and comparison with previously-obtained results and extend the calculation of the self-energies to next-to-leading order in the gluon energy, ω . For the Feynman self-energy/propagator, we present new results which are accurate to all orders in ξ . We compare our exact results with prior expressions for the Feynman self-energy/propagator which were obtained using Taylor-expansions around an isotropic state. We show that, unlike the Taylor-expanded results, the all-orders expression for the Feynman propagator is free from infrared singularities. Finally, we discuss the application of our results to the calculation of the imaginary-part of the heavy-quark potential in an anisotropic quark-gluon plasma.

Week 4 / 11

Open quantum systems approach to the study of quarkonium suppression

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Heavy quarkonium related observables are very useful to obtain information about the medium created in relativistic heavy ion collisions. In recent years the theoretical description of quarkonium in a medium has moved towards a more dynamical picture in which decay and recombination processes are very important. In this talk we will discuss the equations that describe the evolution of the heavy quarks reduced density matrix in different approximations, highlighting the color dynamics that is absent in the Abelian case. Non-relativistic effective field theories are useful tools to study this problem. Using them we will derive the master equation that describes the evolution of quarkonium inside the medium in the case $1/r \gg T$ and we will analyse a specific temperature regime in which all the information needed from the medium can be encoded in two non-perturbative parameters. We will also discuss the relation with classical equations (Langevin and Boltzmann) and how they can help reducing the computational cost of solving the master equation.

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Non-Gaussian flow fluctuations in heavy-ion collisionsGiuliano Giacalone¹¹ *Université Paris-Saclay***Corresponding Author(s):** giulianogiacalone@gmail.com

I present the state-of-the-art of anisotropic flow fluctuations in heavy-ion collisions. Event-by-event fluctuations of flow coefficients are investigated experimentally by means of multi-particle cumulants, which are indicators of the non-Gaussian behavior of the v_n distributions. After a brief review of the theoretical basis underlying cumulants and the related observables, I use selected Pb+Pb and Xe+Xe measurements to show that flow fluctuations are the key probes of the initial fluctuating geometry of the quark-gluon plasma. Eventually, I discuss what the future of flow fluctuations is in view of upcoming large-statistics LHC3 and LHC4 data.

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Transport properties and hadronization of Heavy Quarks from R_{AA} and v_n and their correlations to the bulk collective dynamicsVincenzo Greco¹ ; Salvatore Plumari¹ ; Gabriele Coci¹ ; Vincenzo Minissale²¹ *University of Catania*² *INFN-LNS***Corresponding Author(s):** greco@lns.infn.it

We study the propagation of charm and bottom quarks in the quark-gluon plasma (QGP) by means of a relativistic Boltzmann transport approach. The non-perturbative interaction of heavy quarks is described by means of a quasi-particle approach that entails only a weak dependence of the drag on the temperature. This features, along with hadronization by coalescence, plays a fundamental role to describe simultaneously the experimental data for the nuclear suppression factor R_{AA} and the elliptic flow $v_2(p_T)$ of D mesons at both RHIC to LHC energies.

In particular an hadronization by coalescence predict a very large Λ_c baryon production that impact also the determination of the R_{AA} . In the same scheme, we present predictions for B mesons that allow also a determination of the space-diffusion coefficient that is practically independent on the transport scheme for HQ: Boltzmann vs Langevin.

Focusing on the role of initial state fluctuations to generate high order anisotropic flows $v_3(p_T)$ and $v_4(p_T)$ of D mesons, it will be discussed the role of QCD interaction in developing correlations

between the light and the heavy flavor anisotropic flows (v_n^{light}, v_n^{heavy}) providing novel and powerful constraints for the transport coefficients.

Finally we show how v_1 provides a probe of the very strong initial electro-magnetic (e.m.) fields are created in Ultra-relativistic Heavy-Ion Collision (HIC) that induce a vorticity in the reaction plane that is odd under charge exchange. Even more it can induce a splitting of uncharged D^0 meson and antimeson providing a proof of the QGP phase.

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Anatomy of Azimuthal Angle correlations in Large and Small Systems

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no text

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Symmetric cumulants: Overview of experimental results so far and future directions

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Symmetric cumulants, the novel flow observables which quantify the correlations between event-by-event fluctuations of two different flow harmonics, have been utilized extensively by the experimentalists in recent flow analyses in ultra-relativistic nuclear collisions, both at RHIC and LHC.

These observables provide the strong constraints for the details of QGP's temperature dependence of v_1/s , which is currently heavily studied by the theorists, and to which the individual flow harmonics are nearly insensitive. In addition, symmetric cumulants have a potential to disentangle for the first time the two contributions to anisotropic flow stemming from initial conditions and from the transport properties of the QGP. This in turn could enable the theorists to perform independent modelling and tuning of initial configurations of nuclear collisions and of the system properties of the produced QGP.

In this talk the overview of experimental results collected so far for symmetric cumulants, over a wide range of different collision systems and colliding energies, will be presented. The possibility how to generalize these observables to extract even further independent constraints on initial conditions and QGP properties will be discussed at the end.

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Systematic formulation of far-from-equilibrium relativistic fluid dynamics

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We show that far-from-equilibrium relativistic fluid dynamics may be systematically defined, for arbitrary flow profiles, in terms of a generalized tensorial expansion with transport coefficients that contain an all order resummation in gradients. In this formulation, the transport coefficients of far-from-equilibrium fluid dynamics depend not only on the microscopic properties of the system but also on the nonlinear properties of the underlying state of the fluid itself. In contrast to previous works, no additional assumptions about the symmetries of the flow are necessary. A concrete example of this proposal is constructed using the slow-roll expansion in conformal Israel-Stewart theory. In this case, the novel resummed shear viscosity and relaxation time coefficients decrease with increasing Knudsen number according to formulas that can be readily investigated in current numerical simulations of the quark-gluon plasma formed in ultrarelativistic heavy ion collisions.

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Non-Bessel-Gaussianity and Flow Harmonic Fine-Splitting

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Both collision geometry and event-by-event fluctuations are encoded in the experimentally observed flow harmonic distribution $p(v_n)$ and 2k-particle cumulants $c_n\{2k\}$. In the present talk, we systematically connect these observables to each other by employing Gram-Charlier A series. Also we quantify the deviation of the flow harmonic distribution from Bessel-Gaussianity in terms of the flow harmonic fine-splitting. This study helps us to disentangle the effect of the collision geometry and fluctuations in $v_n\{2k\}$. After that we introduce two applications for this study. We first introduce several estimators for the averaged ellipticity and second we restrict the $v_2\{2\}$, $v_2\{4\}$ and $v_2\{8\}$ phase space.

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Measurements of heavy-flavour correlations and jets with ALICE

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This contribution will focus on the latest heavy-flavour correlation and jet measurements with the ALICE detector in pp, p-Pb and Pb-Pb collisions from the LHC run-2 data.

In particular, the results of azimuthal correlations of D mesons with charged particles in pp collisions at $\sqrt{s} = 7$ and 13 TeV and in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV will be presented. Measurements of multiplicity and centrality dependent azimuthal correlations of heavy-flavour hadron decay electrons with charged particles in p-Pb and Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV will be shown together with the heavy-flavour electron v_2 in p-Pb collisions.

Furthermore, measurements of D-meson tagged jet production in pp collisions at $\sqrt{s} = 7$ TeV including the study of the jet-momentum fraction carried by the D meson will be presented. And the recent results in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV will be reported.

The first measurement of the nuclear modification factor of D-tagged jet in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV will be also discussed.

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Some results and challenges for hydro modelling at RHIC BES

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In this talk I overview the results of our studies of heavy ion collisions at RHIC BES energies in the framework of a viscous hydro + cascade model, vHLE+UrQMD, focusing on the following phenomena:

- Lambda polarization - from RHIC BES to LHC energies
- Femtoscopic observables at RHIC BES

And discuss challenges for hydrodynamic modelling at the lower collision energies (RHIC BES, FAIR, NICA energies)