HK 6: Heavy-Ion Collisions and QCD Phases I

Time: Monday 16:15–18:15 Location: PHIL C 601

Group Report HK 6.1 Mon 16:15 PHIL C 601

Thermalization of heavy quarks in heavy-ion collisions: a fluid-dynamic perspective — •Federica Capellino — GSI Helmholtzzentrum Darmstadt

Heavy quarks (i.e. charm and beauty) are powerful tools to characterize the quark-gluon plasma (QGP) produced in heavy-ion collisions at the LHC and at RHIC top energies. Although they are initially produced out of kinetic equilibrium via hard partonic scattering processes, recent measurements of the anisotropic flow of charmed hadrons pose the question of a possible thermalization of heavy quarks in the medium. By exploiting a mapping between transport theory and hydrodynamics, we developed in recent years a fluid-dynamic description of heavy-quark diffusion in the QCD plasma. In this contribution, I will report the latest results on heavy-quark thermalization in the QGP from our fluid-dynamic perspective. First, we compute the out-of-equilibrium corrections to the heavy-quark phase-space distribution, enabling a consistent description of both integrated yields and momentum spectra of charm hadrons. Second, we explore a 2+1-dimensional fluid-dynamic treatment of charm diffusion to study the development of charm anisotropic flow in both heavy- and light-ion collision systems. Finally, we investigate the universality of the fluid-dynamic description of heavy quarks by searching for attractor solutions that are insensitive to the details of the initial conditions.

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HK 6.2 Mon 16:45 PHIL C 601

Heavy-quark dynamics in the QGP * attractors, thermalization, and universality — •Ruwen Schulz — Physikalisches Institut, Universität Heidelberg

Heavy quarks are produced in hard scatterings at the very beginning of a heavy-ion collision. Consequently, heavy-quarks experience all stages of a heavy-ion collision, and their dynamics are highly sensitive to the properties of the quark*gluon plasma (QGP) phase in particular. Recent studies have demonstrated that a fluid-dynamical description of heavy-quark transport in the QGP, combined with a realistic hadronization and freeze-out procedure, can successfully reproduce experimental particle spectra with remarkable precision. While this success is widely acknowledged, the underlying reasons are not yet fully understood. In this talk, I will discuss the dynamics of heavy-quarks in the QGP, with a focus on possible signs of thermalization*or hydrodynamization*within the finite lifetime of the QGP. Special emphasis will be placed on pre-thermal universal behavior, including scaling features and (hydrodynamic) attractors that may govern heavy-quark evolution even far from equilibrium.

HK 6.3 Mon 17:00 PHIL C 601

Measurement of directed flow (v_1) of D^0 mesons in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.36 TeV — •Alica Marie Enderich for the ALICE Germany-Collaboration — Physikalisches Institut, Heidelberg, Germany

Directed flow is the first harmonic of the azimuthal particle distribution in ultra-relativistic heavy-ion collisions. It is sensitive to the spatial profile of the initial conditions and the pre-equilibrium early time dynamics. Recent predictions indicate that the slope of the directed flow at mid-rapidity for D^0 mesons, driven by the transport of charm quarks in a tilted medium, can be several times larger than the one for light-flavor hadrons. Heavy-ion collisions also generate extremely strong electromagnetic fields, primarily induced by spectator protons. Unlike light quarks, the formation time of charm quarks is comparable to the time at which the magnetic field reaches its maximum strength. As a result, charm quarks are expected to exhibit a much larger charge-dependent directed flow than light quarks.
During Run 2, ALICE provided the first measurement of the charge-dependent v_1 for D^0 mesons in Pb-Pb collisions at LHC. As the experimental measurement was limited by statistics, it is now repeated in Run 3. The reconstruction of the decay topology is improved via ML techniques and the measurement is extended to lower p_{T}.
In this talk, current results on the charge-integrated and charge-dependent v_1 for D^0 mesons are presented. The measurements are compared with theoretical model calculations and results from other experiments.

HK 6.4 Mon 17:15 PHIL C 601

Exploring charm and beauty hadronisation, collectivity, and final-state interactions at the LHC with ALICE — •Biao Zhang for the ALICE Germany-Collaboration — Physikalisches Institut Im Neuenheimer Feld 226 69120 Heidelberg Germany

Beauty and charm quarks, produced in initinal hard scatterings, offer a effective probe to test perturbative QCD (pQCD). We present the first ALICE measurement of B-meson production in pp collisions at $\sqrt{s} = 13.6$ TeV, providing new constraints on pQCD calculations and beauty-quark fragmentation. Charm hadronisation shows striking deviations from universal fragmentation expectations, with charm baryon production posing a persistent puzzle for QCD-based models. In this context, measuring higher-mass excited charm-baryon states provides essential insight into the mechanisms that govern baryon formation. We report the first ALICE reconstruction of excited Ξ_c^0 states via the $\mathrm{D}^0\Lambda$ decay channel, enabled by the large Run 3 pp dataset. This new reconstruction strategy offers enhanced sensitivity to the non-universal nature of charm-quark hadronisation.

Charm-quark collectivity is studied via the first D^0 elliptic-flow measurement in O–O collisions, bridging pp and Pb–Pb systems and constraining heavy-quark transport coefficients.

Finally, new analyses of correlations between Λ_c^+ and D^+ with protons in pp collisions at $\sqrt{s} = 13.6$ TeV, using the large-statistics Run 3 dataset, will also be presented. These measurements open a new avenue for exploring charm*hadron interactions and their role in the formation of charm-bearing bound states.

HK 6.5 Mon 17:30 PHIL C 601

Analysis strategy for a Ξ_c^+ lifetime measurement with ALICE at the LHC — •Simon Pijahn for the ALICE Germany-Collaboration — Pysikalisches Institut, Universität Heidelberg

Experimentally measured charm-baryon lifetime ratios from LHC and Fermilab were long understood to be well described within the Heavy Quark Expansion (HQE) framework. However, in 2018 LHCb reported an Ω_c^0 lifetime almost four times larger than previous measurements, inverting the expected lifetime hierarchy. This result has since been supported by measurements from BELLE II and by more precise LHCb determinations of the Ω_c^0 and Ξ_c^0 lifetimes. These persistent discrepancies highlight the need for additional, precise lifetime measurements for an accurate treatment of higher order terms in the HQE framework and to clarify the experimental situation. As the HQE is strong in predicting lifetime ratios, corresponding measurements of all charm baryons are of interest.
To complement ongoing measurements of charm-baryon lifetimes with the ALICE detector, this contribution presents the analysis strategy and performance for a measurement of the Ξ_c^+ baryon lifetime in pp collisions at $\sqrt{s} = 13.6$ TeV. The analysis employs the Kalman Filter Particle package for secondary vertex reconstruction, boosted decision trees for candidate selection, and a data-driven approach to disentangle prompt from non-prompt contributions.

HK 6.6 Mon 17:45 PHIL C 601

Evolution of perturbations of the energy-momentum tensor during the pre-equilibrium phase of HIC — •Lennart Weber[1], Jie Zhu[1,2,3], and Sören Schlichting[1] — [1]Bielefeld University — [2]CCNU, Wuhan, Inst. Part. Phys. — [3]Hua-Zhong Normal University

Non-eq. Green's functions provide a powerul framework for describing the pre-equilibrium evolution of the QGP created in HICs. They enable a systematic transition from initial state model to hydrodynamic simulations. Previous studies have calculated the Green's functions which propagate initial energy and transverse momentum perturbations on top of a homogeneous background. In this work, we generalize the formalism to include initial transverse tensor perturbations, computed analytically in the free-streaming regime and numerically within the conformal relaxation time approxiamtion from moments of the distribution. The non-eq. Green's functions exhibit damping behavior similar to that found for the energy and momentum perturbations studied in earlier works. The derived Green's functions are further benchmarked against hydrodynamic constitutive relations at late times and then Fourier transformed into coordinate space for practical use in the pre-eq. dynamics package, KoMPoST. Furthermore, we run hydrodynamic simulations and investigate the effects of the pre-eq.

evolution on generation of momentum anisotropy. In summary, this work completes the description of transverse perturbations and provides a consistent framework for evolving the full energy-momentum tensor from the initial time to the onset of hydrodynamics.

HK 6.7 Mon 18:00 PHIL C 601

Validating the Pre-equilibrium Evolution of Heavy Ion Collisions in KøMPøST — •Jens Hügel[1], Sören Schlichting[1], Clemens Werthmann[2], and Victor Ambrus[3] — [1]Universität Bielefeld, Germany — [2]Universiteit Gent, Belgium — [3]Universitatea de Vest din Timișoara, Romania

We explicitly verify the validity of the open source package KøMPøST [1] for modelling the early time dynamics of the QGP in heavy ion collisions. Since KøMPøST is based on the dynamics of a kinetic theory description to implement a macroscopic evolution of the energy-momentum tensor, we assess its applicability by comparing KøMPøST results to fully microscopic calculations in kinetic theory in the relaxation time approximation (RTA) [2]. We find that KøMPøST accurately describes the full 2+1D evolution of the energy-momentum tensor in the pre-equilibrium stage with the exception of the components related to elliptic flow. We investigate possible error sources and attempt to modify KøMPøST in order to bring it into agreement with the full kinetic theory solution.

[1] KoMPoST, Phys.Rev.C 99 (2019) 3, 034910 [2] Ambrus, Werthmann, Schlichting, "Opacity dependence of transverse flow, preequilibrium, and applicability of hydrodynamics in heavy-ion collisions" Phys.Rev.D 107 (2023) 9, 094013