

INITIAL TIME τ_0 CONSTRAINED BY HIGH- p_\perp DATA*

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We show that high- p_\perp R_{AA} and v_2 are way more sensitive to the initial time of fluid-dynamical expansion τ_0 than the distributions of low- p_\perp particles, and that the high- p_\perp observables prefer relatively late $\tau_0 \sim 1$ fm/c. To calculate high- p_\perp R_{AA} and v_2 , we employ our DREENA-A framework, which combines state-of-the-art dynamical energy loss model with 3+1-dimensional hydrodynamical simulations. Elliptic flow parameter v_2 is also more sensitive to τ_0 than R_{AA} . This presents an example of applying QGP tomography to constrain a bulk QGP parameter with high- p_\perp observables and related theory.

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1. Introduction

Quark–gluon plasma (QGP) is a new form of matter that consists of interacting quarks, antiquarks, and gluons. It is formed in ultrarelativistic heavy-ion collisions at the Relativistic Heavy-Ion Collider (RHIC) and the Large Hadron Collider (LHC). In these experiments, the bulk properties of QGP are usually explored by low- p_\perp observables. Rare high-energy probes are, on the other hand, almost exclusively used to understand the interactions of high- p_\perp partons with the surrounding QGP medium. We are advocating high- p_\perp QGP tomography, where bulk QGP parameters are

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jointly constrained by low- and high- p_{\perp} physics. For instance, we have previously demonstrated how the anisotropy of the QGP formed in heavy-ion collisions is reflected in the high- p_{\perp} observables [1].

In these proceedings, we analyse how high- p_{\perp} R_{AA} and v_2 depend on the initial time τ_0 , *i.e.* the time of onset of fluid-dynamical expansion, complementing the more detailed study provided in Ref. [2]. The dynamics before thermalisation, and τ_0 , and, therefore, the associated energy loss phenomena, are not established yet. To avoid speculation and to provide a baseline calculation for further studies, we assume free streaming of high- p_{\perp} particles before τ_0 and neglect the pre-equilibrium evolution of the medium (we explore the effects of pre-equilibrium evolution elsewhere [2]). After τ_0 , the QCD medium is described as a relativistic viscous fluid and high- p_{\perp} probes start to lose energy through interactions with this medium. Consequently, the initial time τ_0 is an important parameter, which affects both the evolution of the system and interactions of the high- p_{\perp} particles with the medium.

We describe the medium evolution by the 3+1-dimensional viscous hydrodynamical model from Ref. [3] and we use the optical Glauber model for the initial state (see [2] for more details). The model parameters are tuned so that the transverse momentum distributions of charged particles for six different τ_0 values in the range from 0.2 fm/c to 1.2 fm/c agree with experimental data (see Fig. 1 in [2]), which is also true for p_{\perp} -differential elliptic flow parameter $v_2(p_{\perp})$ (shown in the low-momentum part ($p_{\perp} < 2$ GeV) of the lower panels of Fig. 1).

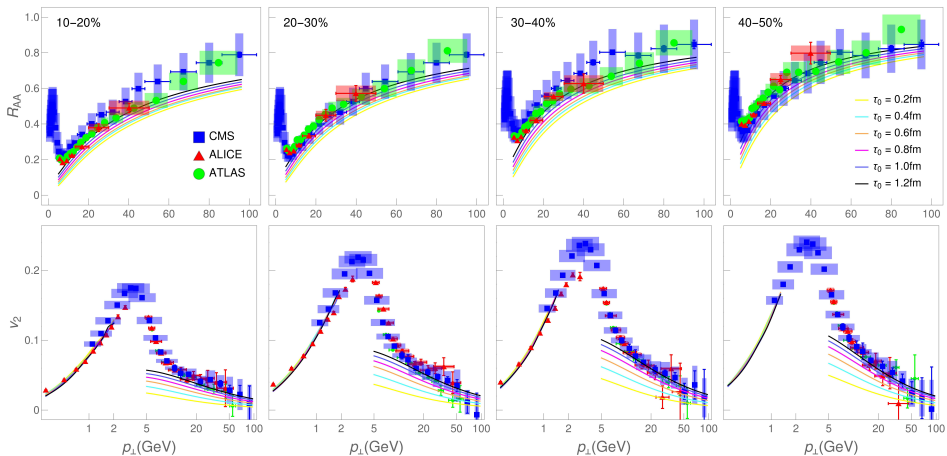


Fig. 1. Charged hadron DREENA-A R_{AA} (upper panels) and v_2 (lower panels) predictions, generated for six different τ_0 (indicated on the legend), are compared with ALICE [4, 5], ATLAS [6, 7], and CMS [8, 9] data. Four columns, from left to right, correspond to 10–20%, 20–30%, 30–40%, and 40–50% centralities at $\sqrt{s_{NN}} = 5.02$ Pb+Pb collisions at the LHC.

To evaluate the high- p_\perp parton energy loss, we use our recently developed DREENA-A framework, the details of which are outlined in [10]. The resulting predictions for charged hadron R_{AA} in four different centrality classes, and for τ_0 in the range of 0.2–1.2 fm, are shown in the upper panel of Fig. 1, and compared with experimental data. In the lower panel of Fig. 1, we show a similar comparison of predicted high- p_\perp v_2 to data. In distinction to the low- p_\perp distributions, we see that high- p_\perp predictions can be resolved against experimental data, and that the later onset of fluid dynamics is clearly preferred by both R_{AA} and v_2 . This resolution is particularly clear for v_2 predictions, which approach the high- p_\perp tail of the data, as τ_0 is increased. It also increases for higher centralities, as analysed below.

What is the reason behind such sensitivity? One proposal [11] was that jet quenching may start later than the fluid dynamical evolution. We test this scenario by introducing a separate quenching start time $\tau_q \geq \tau_0$. In Fig. 2(A) we show the high- p_\perp R_{AA} and v_2 in 20–30% centrality for $\tau_0 = 0.2$ fm, and τ_q values in the range of 0.2–1.2 fm. The sensitivity to τ_q is similar in other centralities, for larger τ_0 and for heavy flavour. R_{AA} shows similar sensitivity to τ_q as to τ_0 ; compare Figs. 2(A) and 1. The v_2 is surprisingly insensitive to τ_q , and way below the data, not supporting this scenario.

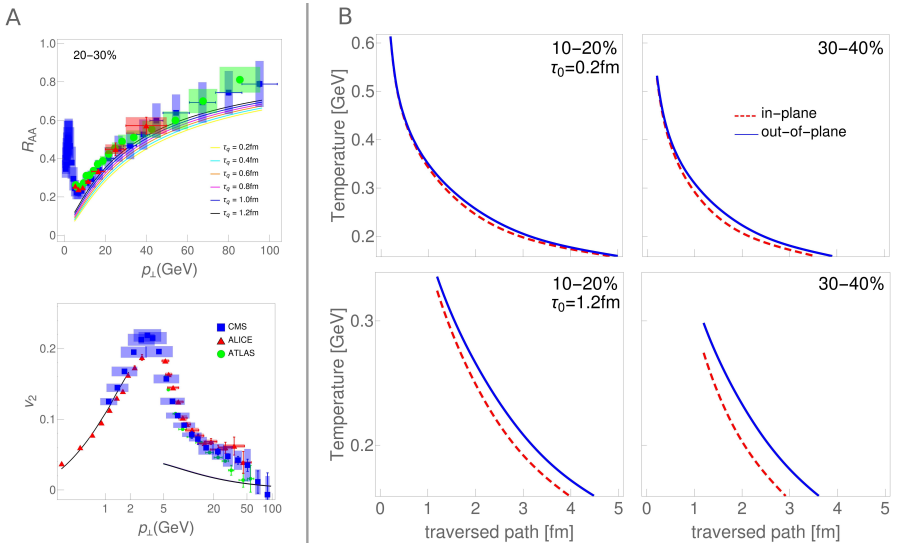


Fig. 2. (A) DREENA-A predictions for charged hadron R_{AA} (left) and v_2 (right) in 20–30% centrality class of $\sqrt{s_{NN}} = 5.02$ TeV Pb+Pb collisions at the LHC, generated for $\tau_0 = 0.2$ fm and six different τ_q . The predictions are compared with ALICE [4, 5], ATLAS [6, 7], and CMS [8, 9] data. (B) The average temperature along the jet path traversing the system in out-of-plane and in-plane directions.

We next investigate if the origin of the sensitivity is due to the difference in the temperature profiles. For this, we evaluate the average temperature along the paths of jets travelling in-plane and out-of-plane directions. In Fig. 2(B), we show the resulting temperature evolution in 10–20% and 30–40% centrality for $\tau_0 = 0.2$ and 1.2 fm. As τ_0 is increased, the differences between in-plane and out-of-plane temperature profiles also increase. Since v_2 is proportional to the difference in suppression along in-plane and out-of-plane directions, a larger difference along these directions leads to larger v_2 , and causes the observed dependency on τ_0 . As well, for fixed τ_0 , increasing τ_q hardly changes v_2 since at early times, the average temperature in- and out-of-plane directions is almost identical, and no v_2 is built up at that time in any case. Furthermore, the more peripheral the collision, the larger the difference in average temperatures, which leads to higher sensitivity of v_2 to τ_0 as seen in the lower panels of Fig. 1. Consequently, the temperature profile differences are a major contributor to such sensitivity.

We here presented how high- p_\perp theory and data can be used to constrain a parameter weakly sensitive to bulk QGP evolution. We used high- p_\perp R_{AA} and v_2 to infer that experimental data prefer late onset of fluid dynamical behaviour. v_2 shows a higher sensitivity to τ_0 than R_{AA} , and we showed that v_2 is affected by τ_0 due to differences in the in- and out-of-plane temperature profiles. This demonstrates inherent interconnections between low- and high- p_\perp physics, supporting our proposed QGP tomography approach.

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