Extraction of heavy-flavor transport coefficients in QCD matter

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The heavy charm and bottom quarks are excellent probes of the transport properties of the quark-gluon plasma (QGP) as produced in ultra-relativistic heavy-ion collisions (URHICs). Due to their large masses heavy quarks undergo a Brownian motion whose associated transport coefficients characterize the coupling strength to the QGP. Furthermore, an incomplete thermalization implies that the modifications of the heavy-quark (HQ) spectra in URHICs (relative to *pp* collisions) retain a memory of the interaction history which can serve as a direct gauge of the interaction strength. However, a quantitative extraction of the transport coefficients from the finally observed spectra of D- and B-mesons requires good control over several other components that affect these spectra. These include initial-state cold-nuclear-matter modifications of the HQ spectra, the mechanisms leading to the hadronization of the heavy quarks when the QGP converts into hadronic matter, the transport in the hadronic phase, and the modeling of the space-time evolution of the fireball through which the heavy-flavor particles diffuse.

To quantify the impact of these auxiliary components in the heavy-flavor transport models, an EMMI rapid reaction task force was formed where several of the active groups in the field participated [1]. To begin with, a predefined charm-quark transport coefficient (perturbative QCD Born scattering with K-factor 5, or "pQCD*5") has been used by all groups in their QGP evolution and hadronization models for semi-/central Pb-Pb(2.76TeV) collisions. Up to two outliers, a promising agreement between the results of the different groups emerged at the level of the charm-quark nuclear modification factor (R_{AA}) and elliptic flow (v_2). A larger relative uncertainty among the model results is found after applying the different hadronization models, which include various forms of recombination of the charm quark with thermal anti-quarks, as well as independent fragmentation. In attempt to arrive at a theoretical error estimate, an average of the model results for the D-meson R_{AA} and v_2 has been performed (excluding the 2 outliers) and compared to experimental data from the ALICE [2] and CMS [3] collaborations, see Fig. 1. The average suggests that the current theoretical modeling error amounts to about 20%, which is rather encouraging. The comparison also shows that especially the elliptic flow is much underestimated by the underlying pQCD*5 transport coefficient, implying that the corresponding diffusion coefficient of D_s $(2\pi T) \sim 6$ is clearly too large, i.e., a much stronger coupling of the charm quarks to the collectively expanding QGP is required.

Closer inspection of the employed recombination models for the hadronization of charm quarks into D mesons reveals that satisfying basic conservation laws (such as 4-momentum) and the correct thermal equilibrium limit [4] is critical for reliable results.

This project has laid the groundwork for future precision studies and extractions of heavy-flavor transport coefficients in QCD matter from heavy-ion collisions. Follow-up activities are underway and will take full advantage of open heavy-flavor data from the high-luminosity LHC run-3 and -4.

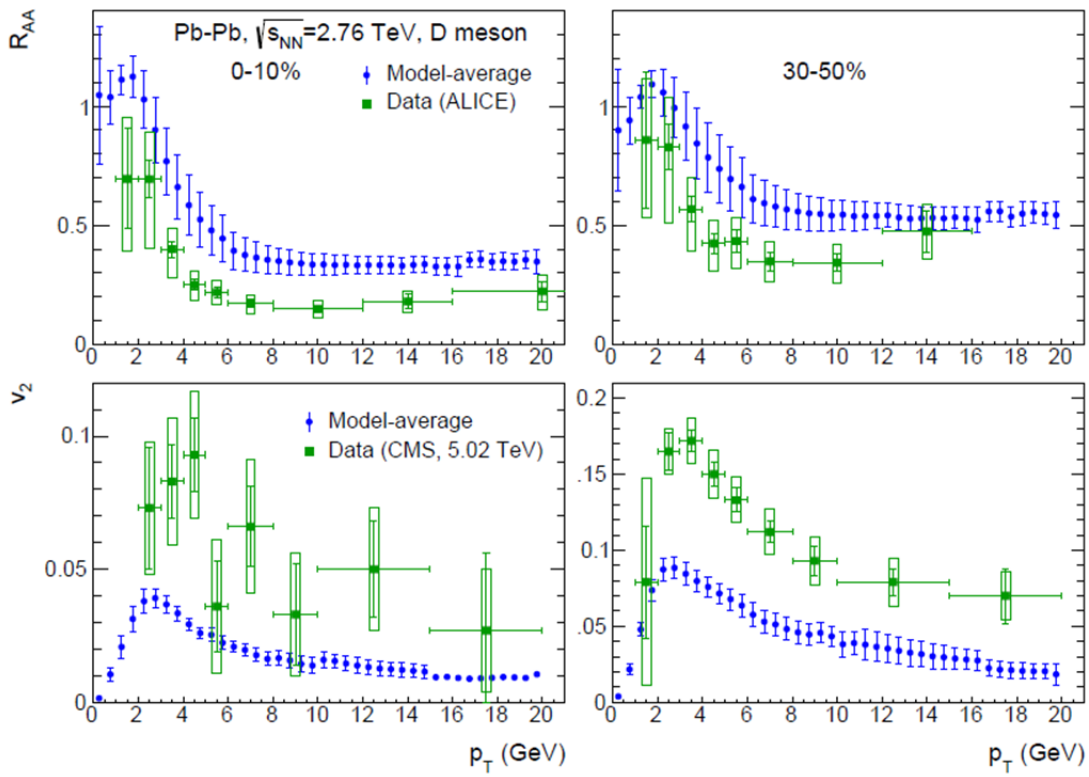

FIG. 1. Average nuclear modification factor (upper panels) and elliptic flow (lower panels) of D mesons in 2.76TeV Pb-Pb collisions for different fireball + hadronization models using a common c-quark transport coefficient in the QGP, compared to ALICE and CMS data.

[1] R. Rapp, P.B. Gossiaux, A. Andronic, R Averbeck, and S. Masciocchi (eds.) *et al.*, arXiv:1803.03824.

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[4] L. Ravagli and R. Rapp, Phys. Lett. B **655**, 126 (2007).