Charm production: constraint to transport models and charm diffusion coefficient with ALICE

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Abstract. New measurements of D mesons with the ALICE detector, interpreted with theoretical models, can give additional information about the spatial diffusion coefficient, a characteristic of the QGP medium. The relevant ingredients to the models can be assessed by comparing the predictions with diverse measurements of charmed hadrons. This contribution discusses the comparison of measurements with a large set of predictions and the role of the different ingredients implemented in the theoretical models, as well as the conclusions about the spatial diffusion coefficient.

1 Introduction

Heavy quarks are particularly useful probes for the properties of the quark-gluon plasma (QGP). Produced dominantly in the initial hard scatterings of a heavy-ion collision, they experience the evolution of the medium and can still be identified afterwards when measuring hadrons with heavy valence quarks. Due to the excellent primary vertex resolution and particle identification capabilities, ALICE is well suited to measure a range of different charmed hadrons. With the help of theoretical models, these measurements provide information about the interaction of heavy quarks with the QGP and thus its properties.

In most available models, the interaction of heavy quarks with the medium is treated as a series of scatterings of the heavy quarks. They can be considered as interactions with the quarks and gluons or with effective scattering centers. Here, a distinction can be made between elastic $2 \rightarrow 2$ scatterings and inelastic $2 \rightarrow 3$ scatterings producing an additional gluon. Elastic (or collisional) interactions happen independently, while the gluons from inelastic (or radiative) interaction might interfere. This can mean that the energy exchange is not necessarily proportional to the path length. For particles much faster than the surrounding medium, the radiative interaction is expected to be dominant.

The interaction via individual scatterings leads to a description of the propagation through the medium with the Boltzmann-, Fokker-Planck-, and Langevin transport equations in the different models. These make use of different parameter sets, which can however be related to each other. A useful parameter here is the spatial diffusion coefficient D_{s}, which is related to the mean squared displacement by $\langle \vec{r}^2 \rangle = (2d)D_s t$, where d is the number of spatial dimensions and t the time. This quantity at a reference temperature (e.g. 155 MeV) is a characteristic of the medium and can be constrained by the measurements of charmed hadrons.

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2 Measurements of charmed hadrons

The main observables are the nuclear modification factor R_{AA} and the flow coefficients v_n. However, these are not only dependent on the interaction of heavy quarks with the medium but can also be affected by other effects, such as modifications due to nuclear parton distribution functions (nPDFs), or the hadronization process. These effects need to be understood to disentangle them.

2.1 Nuclear Parton Distribution Functions

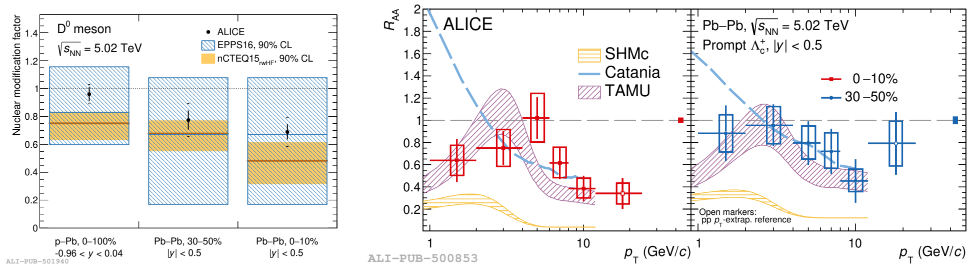

Figure 1. Left: p_T-integrated R_{AA} for D^0 mesons [1]. Right: R_{AA} of Λ_c compared with models [2].

In the most recent measurement of ALICE [1], D^0 mesons are measured at midrapidity in Pb–Pb collisions down to $p_T = 0$. This makes it possible to calculate the integrated yield without extrapolation uncertainties. The p_T-integrated nuclear modification factor is sensitive to differences in the production of charm quarks between pp and Pb–Pb collisions and thus to the nPDFs, in particular to the shadowing effects that reduce the charm production in Pb–Pb and in p–Pb with respect to the production in pp collisions. Figure 1 (left) shows that the measurements performed in Pb–Pb collisions indeed deviate from one and does so in agreement with calculations based on nPDFs. However, deviations from pure binary collision scaling can also appear due to the charm quarks ending up in different hadron types in Pb–Pb collisions compared to the pp reference.

2.2 Charm hadrochemistry

To test the contribution from different charmed hadron species, several measurements were performed. Figure 1 (right) shows the nuclear modification factor for Λ_c^+ baryons [2] compared with theoretical models. The TAMU calculations are in fair agreement with the measurement while the result for the Catania model somewhat overestimates the low-p_T values.

The measurement of D_s^+ mesons [3] leads to a similar result as shown in figure 2 (left) with many models describing the shape of the R_{AA} well. The peak of the R_{AA} seems to be shifted towards higher p_T compared to the non-strange D mesons and even further for the Λ_c^+. This would be consistent with the generic expectation that participation in the flow of the medium should push heavier particles towards higher transverse momenta.

This connection to the collective expansion of the medium can be seen in the measurements of the elliptic and triangular flow coefficients of D_s^+. The measurement of the elliptic flow is shown in figure 2 (right). The values for v_2 are similar to those of the non-strange D mesons. This provides important constraints about the interplay of the elliptic flow of

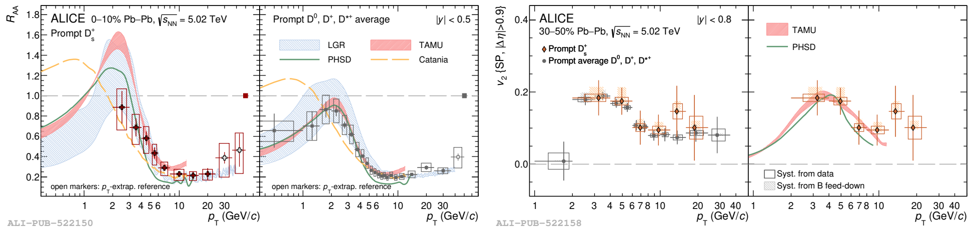

Figure 2. R_{AA} (left) and v_2 (right) of D_s^+ mesons compared with models [3].

the charm quarks themselves and the surrounding medium where they hadronize. The two models, which include coalescence effects describe the v_2 well.

A comparison of the results with the statistical hadronization model [4] shows that the yields are consistent with thermal production with the exception of Λ_c^+. This result could be explained by the existence of additional charmed baryon resonances decaying into Λ_c^+.

3 Discussion of model comparisons and the spatial diffusion coefficient

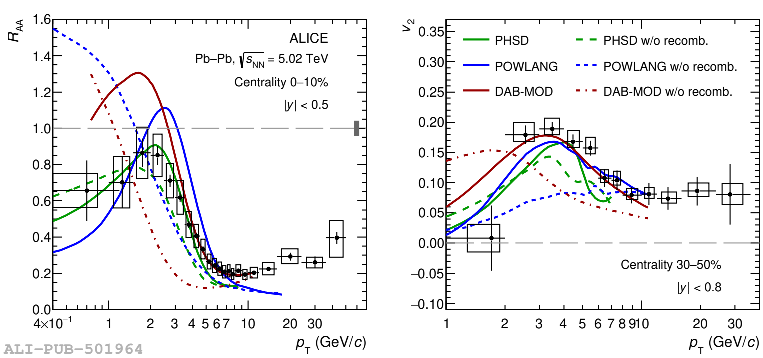

Figure 3. Comparison of R_{AA} and v_2 measurements with models with recombination processes turned on and off [1].

Further knowledge about the role of the different ingredients implemented in theoretical models is gained comparing the p_T-differential R_{AA} [1] and v_2 [5] of non-strange D mesons with models, removing key ingredients. As shown in figure 3, recombination effects are an important ingredient in the models to describe production and flow. The radiative contributions to the interaction are particularly important at higher p_T when attempting to describe a large p_T-range.

The path-length dependence of heavy-quark interactions with the medium was investigated by measuring leptons from heavy-flavor decays in Xe–Xe collisions [6]. Here, the path length scales differently with centrality and multiplicity compared with Pb–Pb collisions. Interestingly, the resulting R_{AA} takes on very similar values between Pb–Pb and Xe-Xe collisions at the same multiplicity. However, comparison of the measurement with a larger number of models is necessary for more thorough conclusions about the scaling with the path length.

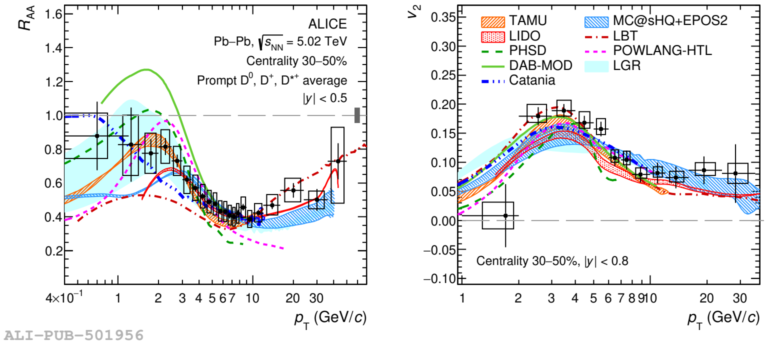

Figure 4. Comparison of R_{AA} and v_2 measurements in semiperipheral events with different models [1].

To understand the influence of the spatial diffusion coefficient, several models were compared to the R_{AA} and v_2 measurements in central and peripheral collisions as in figure 4. The comparison was done for $p_T < 8$ GeV/c, where observables are more sensitive to the diffusion and hadronization processes of charm and in order to have a more direct comparison for models covering different p_T ranges. As the nuclear modification factor is in general influenced by additional ingredients to the models other than the spatial diffusion coefficient, models were qualified by a reasonable agreement with data, i.e. a reduced $\chi^2 < 5$ for the R_{AA} and $\chi^2 < 2$ for the v_2. Thereby, uncertainties both in the model and the measurements are considered.

The models, which provide a reasonable description of the data by this criterion are TAMU [7], MC@sHQ+EPOS2 [8], LIDO [9], LGR [10], and Catania [11]. The corresponding values for the spatial diffusion coefficient at T_c are $1.5 < 2\pi D_s T_c < 4.5$. These values correspond to relaxation time for charm quarks of $\tau_c \approx 3 - 8$ fm/c, i.e. during the lifetime of the QGP.

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