

Conference Paper

Angular correlations with charmed hadrons in the Monte-Carlo model with string repulsion

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Abstract

Recent experimental results revealed large elliptic flow of the charmed hadrons at LHC energies, unexpectedly similar to that of the charged pions. The mentioned measurements are often interpreted using transport models, which incorporate dissociation and recombination mechanisms for charm quarks. In this report, a modified version of the Monte Carlo model with string repulsion is used to calculate azimuthal correlations with charmed hadrons. The string repulsion mechanism may provide significant angular correlations and can be considered as an alternative to thermalization picture.

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1. Introduction

This is usually argued that heavy quarks (charm and beauty) are predominantly produced at the very early stages of a heavy-ion collision via the hard scattering processes and, therefore, they experience all subsequent stages of the system evolution (see some recent reviews in [1, 2]).

A rather strong modification of the transverse momentum (p_T) distributions of heavy-flavour hadrons in heavy-ion collisions in comparison to pp collisions, was observed in the experiments at RHIC [3, 4] and LHC (see [5] for ALICE data). It may be considered as one of the indications of the interactions of heavy quarks with the medium. A large suppression of heavy-flavour hadron yields for $p_T > 4-5$ GeV/c in central collisions is usually attributed to parton energy loss in the medium [6–8]. Another evidence comes from the recent measurements of the second Fourier coefficient v_2 (called an elliptic flow) of D mesons in Pb–Pb collisions at LHC energies ($\sqrt{s_{NN}}=2.76$ and 5.02 TeV) [9]. It was found that the magnitude of the v_2 turned out to be similar to that of charged pions. These measurements are usually compared with theoretical model calculations which implement charm-quark transport in a hydrodynamically expanding medium.

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2. The MC model with string repulsion

In the current work, we try to qualitatively describe the behaviour of D mesons in the framework of the Monte Carlo (MC) model with string repulsion. We will try to separate so-called “soft” and “hard” sources of particle production, and will see how the interplay between these two contributions is reflected on some observables.

The “soft” part of particle production comes from the hadronization of the quark-gluon strings. The strings are formed at the early stages of hadron-hadron collisions, they may overlap in case of sufficiently high densities and interact by repelling or attracting each other, depending on the direction of the color fluxes [10]. For instance, in the hypothesis of repulsive interaction, strings may acquire, before the hadronization, an additional transverse boost. This produces additional transverse momenta to the particles formed in string decays over a wide range of rapidity, thus leading to modification of observables. Details of the Monte Carlo implementation of this model are described in [11], and results on azimuthal asymmetry of two-particle correlations obtained with this model are shown in [12].

In order to parametrize the spectra of particles coming from breaking of a string in its rest frame, the identified particle spectra of pions, kaons and protons measured by ALICE [13] in proton-proton collisions at $\sqrt{s} = 2.76$ TeV were used. Namely, for each particle species, the exponential fit for the soft part of the spectrum (usually at $p_T < 1$ GeV/c) was performed, and then utilized in the MC model to assign the transverse momentum for the particles emitted from the strings. The remaining part of each spectrum, obtained after subtraction of the exponential part, was used as a “hard” component for corresponding particle species. This component comes from the hard scatterings of partons, and for high p_T the spectra have a power-law shape, as expected from the perturbative QCD calculations.

The important feature of the model presented here is that the hard part *is not affected* by the transverse boosts of the strings, acquired due to the repulsive interaction. As a consequence, in the non-peripheral (i.e. central) nucleus-nucleus collisions, where strings accumulate significant transverse boosts, the soft component of the spectrum is being “blue-shifted” onto the hard one, leading to the modification of the overall shapes of the spectra in nucleus-nucleus collisions, simulated in this MC model.

There is a very small probability for the quark-gluon string to break into charm and anti-charm quark pair via the Schwinger mechanism ($\sim 10^{-11}$, [14]). Nevertheless, we assume in the present MC model, that $c\bar{c}$ quark pairs can be produced in the string hadronization process with a sufficient probability, providing the exponential part of the spectra of charmed hadrons, which is supplemented by the hard part. Such

growth of the open charm production can be explained by the modification of the string tension due to string overlapping and interaction in a form of fusion. String breaking into $c\bar{c}$ quark pairs was studied in [15].

As a proxy for the charmed hadrons, D mesons were taken, and their spectrum measured in pp collisions by ALICE [16] was used to parametrize the MC model, in the same manner as spectra of π , K, p.

For the simplified version of the MC model used in this work, it is supposed also that it is possible to neglect resonance decays, jets and final state effects like rescattering of hadrons.

3. Nuclear modification factor for A–A collisions

In order to compare to the experiment, it is interesting to capture the p_T -dependence of the nuclear modification factor (R_{AA}) in the framework of the string repulsion model. The R_{AA} factors, calculated within the MC model for Pb–Pb collisions in centrality range of 20–40% for pions, kaons and protons, are shown in Figure 1 as lines of different colors. Markers represent values measured by ALICE [17]. Correspondence between the model and data is only qualitative. However, it can be seen that the so-called mass ordering is correctly reproduced by the MC model, and also a decreasing trend is observed after some maximum value for each particle species, similarly to data. This change of behavior reflects the interplay between the soft and hard components, implemented in the MC model.

Some differences for pions at small p_T could come from decays of resonances, which are switched off in the model. Peaks for π , K and p in the model calculations are shifted to the right with respect to data points, indicating that radial expansion is slightly stronger in the simulation than in data. Also, the known increasing trend of R_{AA} , observed in data for $p_T > 8$ GeV/c up to very high p_T values, is not captured in the given simulations, since we do not introduce any modification of the “hard” component in this variant of the model.

4. Differential elliptic flow

The mass ordering of particle species was observed also in the differential elliptic flow, $v_2(p_T)$, for instance in Pb–Pb collisions [18]. Recently, the $v_2(p_T)$ has been measured also for D meson in semi-central Pb–Pb events [9], and the values were found to be similar to that of lighter particles.

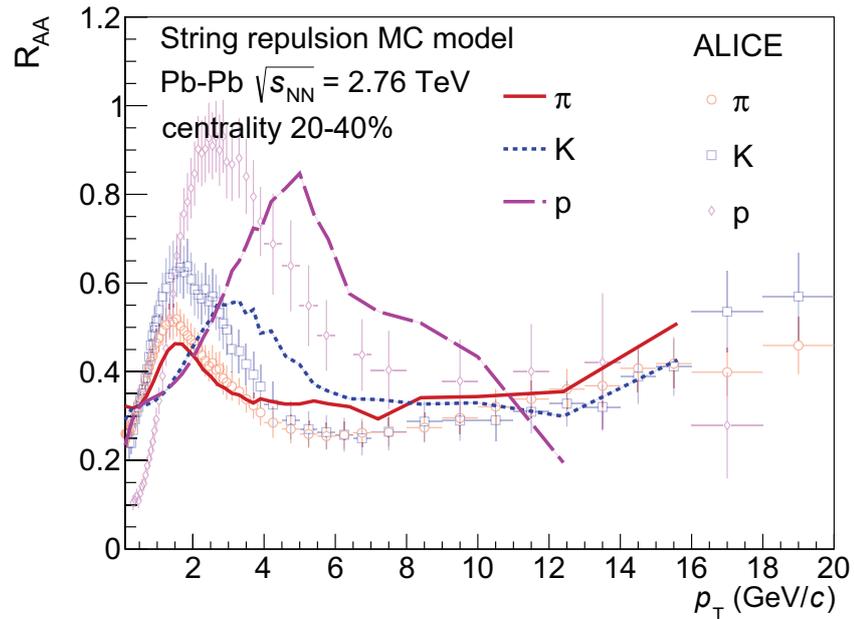


Figure 1: R_{AA} for Pb-Pb collisions in centrality range of 20–40%. Model calculations (lines) are compared with ALICE data (markers).

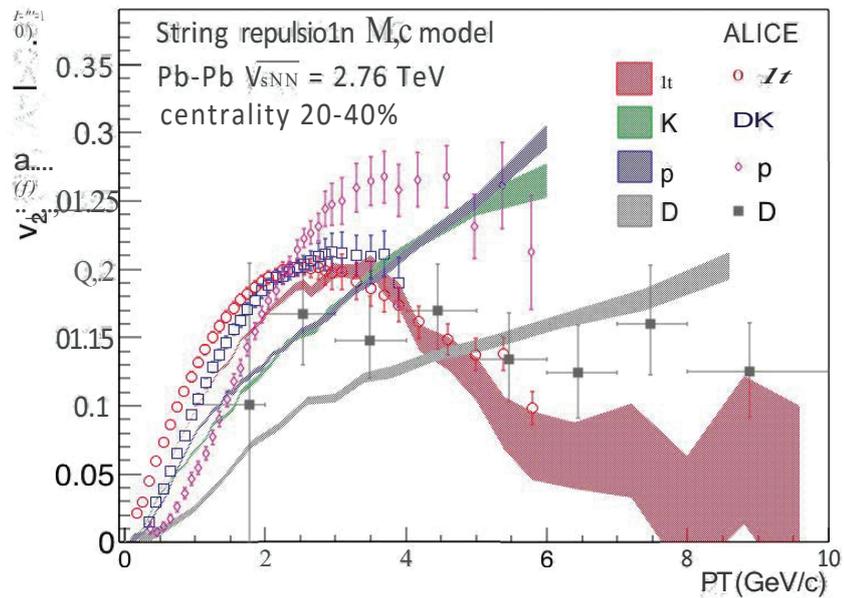


Figure 2: Differential elliptic flow for π , K, p and D mesons in centrality range of 20–40% in the MC model. Markers are for ALICE data (for D mesons, centrality range in experiment was 30–50%).

In the present MC model, the mass ordering of v_2 obtained for different particle species is qualitatively similar to the experiment (Figure 2). Data points for D mesons are also fairly described in the model. For pions, after some maximum value, one may see a decreasing trend of v_2 at high p_T , as it was observed for R_{AA} in Figure 1. This is due to increasing fraction of the hard contribution at higher p_T , which is not affected by the “collective” repulsive motion of the strings. In order to see the same change of

behavior for other particle species, more subtle tuning of the interplay between soft and hard components of the particle production is needed.

5. Conclusions

It is shown that some certain signatures of collectivity, like R_{AA} or elliptic flow, observed experimentally in A-A collisions, can be obtained in the model with the repulsing strings. Namely, the model qualitatively reproduces the mass ordering of the nuclear modification factor and the azimuthal flow both for the light flavours and for heavier hadrons, for instance, D mesons.

The main challenge for the model is to reproduce correctly the interplay between soft and hard contributions in the intermediate p_T range (from ≈ 1 to 8 GeV/ c , depending on the particle species).

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