PROCEEDINGS OF SCIENCE

Measurements of charm meson production in p+p and Au+Au collisions by the STAR experiment

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Charm quarks possess a large mass and thus they are expected to be primarily produced during the initial stages of heavy-ion collisions. Hot and dense nuclear matter, usually referred to as the Quark-Gluon Plasma (QGP), can also be created in these collisions. Therefore, properties of the QGP can be studied via the energy loss and anisotropy of charm quarks, which is closely related to the nature of interactions between charm quarks and the medium.
In these proceedings, we will report the most recent measurements of D^0, $D^{\pm}$ and D_s production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. These open charm mesons are reconstructed via their hadronic decay channels, where the daughter particles are tracked and identified with excellent precision by the STAR experiment at RHIC. At high transverse momentum region and in central Au+Au collisions, D meson production is strongly suppressed compared to that in p+p collisions, indicating substantial energy loss of charm quarks in the medium. In addition, measurements of elliptic and triangular anisotropies of D meson azimuthal distributions indicate that charm quarks have gained significant flow in the QGP. These results are compared to those of light hadrons as well as theoretical calculations. Moreover, charm quarks participate in coalescence hadronization in the QGP as suggested by the enhanced D_s to D^0 yield ratio in Au+Au collisions compared to that in p+p collisions.

The European Physical Society Conference on High Energy Physics
5-12 July
Venice, Italy

*Speaker.

PoS(EPS-HEP2017)650

1. Introduction

Quark-Gluon Plasma (QGP) is a state of hot and dense nuclear matter composed of deconfined quarks and gluons. This matter is expected to be present in the early universe and can be currently created in relativistic heavy-ion collisions at both the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC).

Charm quarks are created mainly in the initial stages of heavy-ion collisions and subsequently travel through the hot, dense matter. Thus they are excellent probes of the properties of the QGP. Measurements of charm meson production in heavy-ion collisions provide a great opportunity to study the charm quark energy loss in the hot medium, which is directly related to the transport coefficients of the QGP. Furthermore, collective behavior of charm quarks in the QGP is sensitive to the degree of thermalization in the medium, and can be used to constrain the heavy-flavour quark spatial diffusion coefficient.

2. Experimental setup

Results on open charm meson production in Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV, with comparison to that in p+p collisions at $\sqrt{s} = 200$ GeV, are presented in these proceedings. These were measured by the Solenoidal Tracker at RHIC (STAR) experiment designed to study the strongly interacting matter created in heavy-ion collisions. Charged particles emerging from these collisions are tracked and identified with great precision at STAR. Main sub-systems used for particle reconstruction and identification are the Time Projection Chamber [1], the Time-Of-Flight detector [2] and the Heavy Flavor Tracker (HFT) [3]. In particular, HFT, the high-precision silicon vertex detector installed at the center of STAR for data taking in years 2014-2016, was of pivotal importance for the analyses presented in these proceedings. It greatly improves the track pointing resolution and enables the topological reconstruction of the secondary vertices of open charm meson decays through hadronic channels.

3. Energy loss of open charm mesons in Au+Au collisions

A mass and color charge ordering of the parton energy loss in the hot medium is predicted, i.e. heavy-flavour quarks are expected to lose less energy than light-flavour quarks and gluons. Such energy losses can be quantitatively studied by using the nuclear modification factor $R_{\rm AA}$, defined as the ratio between the invariant particle yields measured in Au+Au and p+p collisions (where no QGP is expected to be created), scaled by the average number of binary collisions in the investigated centrality interval.

The nuclear modification factors of open charm mesons in the 0-10% most central Au+Au collisions are shown in figure 1 [4], and compared to theoretical predictions. The $R_{\rm AA}$ of $\rm D^0$ and $\rm D^{\pm}$ are in agreement with each other and can be qualitatively described by the displayed theoretical predictions, which include strong interactions of the charm quark with the medium. As can be seen, $\rm D^0$ and $\rm D^{\pm}$ are strongly suppressed at high transverse momenta ($p_{\rm T}$) and this suppression decreases towards lower $p_{\rm T}$.

PoS(EPS-HEP2017)650

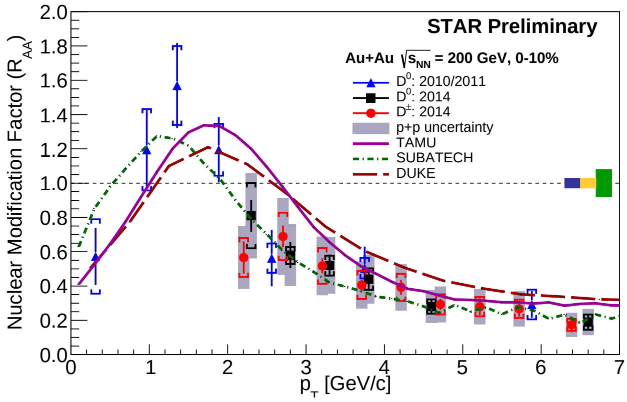

Figure 1: The D^0 and $D^{\pm}$ R_{AA} in the 0-10% most central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV compared to theoretical calculations. Data from 2010/2011 and theoretical predictions are taken from Ref. [4].

4. Elliptic and triangular anisotropies of open charm mesons

In order to study the collective behavior of partons in the QGP, elliptic (v_2) and triangular (v_3) anisotropies of hadrons are measured. These are the second and the third coefficients of the Fourier decomposition of the azimuthal distribution of the particle yield with respect to the event plane. They are sensitive to the hydrodynamic properties of the hot medium.

In figure 2, D^0 meson v_2 (left) and v_3 (right) in Au+Au collisions are shown as a function of p_T, and compared to those of light hadrons. Both of them are non-zero, indicating that charm quarks have gained significant flow in the QGP via strong interactions with the medium. Additionally, v_2 shows a mass ordering for $p_T < 2$ GeV/c and is consistent between open charm mesons and light mesons for $p_T > 2$ GeV/c.

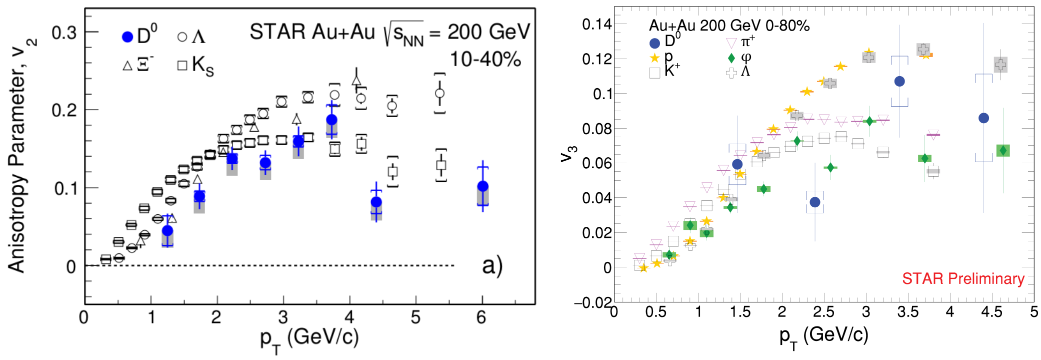

Figure 2: The elliptic anisotropy v_2 in the 10-40% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [5] (left) and triangular anisotropy v_3 in the 0-80% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV (right) as a function of p_T for D^0 compared to those of light hadrons.

5. Strangeness enhancement for charm mesons

Due to their earlier freeze-out, strange-charm mesons (D_s) are more sensitive to the properties of the QGP than non-strange charm mesons (D^0). Enhancement of the D_s to D^0 yield ratio in Au+Au collisions compared to that in p+p collisions is expected if the quark coalescence mechanism plays an important role in the charm quark hadronization.

Figure 3 shows the yield ratios of D_s to D^0 in 0-10% and 10-40% central Au+Au collisions as a function of p_T, compared to the world-data average of the charm quark fragmentation ratio (0.132) in elementary collisions [6] and model predictions. Results in the two centrality intervals are comparable within uncertainties. The PYTHIA prediction and the fragmentation ratio in elementary collisions are significantly lower than the Au+Au results in both centrality intervals. The Statistical Hadronization Model (SHM) [7] is consistent with data, predicting an enhanced yield ratio of about 0.338. The measurement in the 10-40% centrality interval for $p_T < 4$ GeV/c is underestimated by the TAMU model calculation [8], which includes the coalescence mechanism.

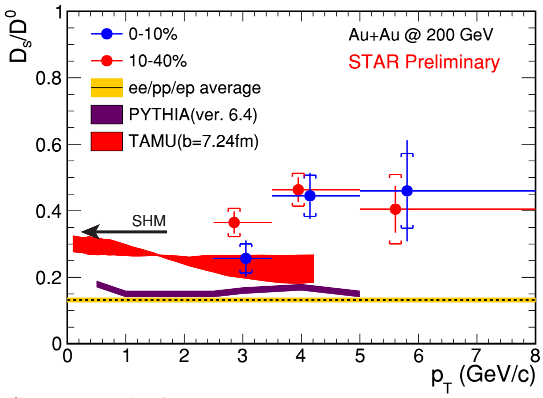

Figure 3: The yield ratios of D_s to D^0 in the 0-10% and 10-40% most central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV as a function of p_T, compared to fragmentation baseline [6], PYTHIA, Statistical Hadronization Model (SHM) [7] and TAMU [8] predictions.

6. Summary

Open charm mesons are reconstructed via their hadronic decay channels thanks to the excellent track pointing resolution provided by the HFT at the STAR experiment. Results on the nuclear modification factor in 0-10% central Au+Au collisions show strong suppression of D meson production at high p_T compared to that in p+p collisions, indicating substantial energy loss due to strong parton-medium interactions. Comparison of v_2 and v_3 between D^0 and light hadrons suggests that charm quarks have gained significant flow when traversing the medium. The enhancement of the D_s to D^0 yield ratio implies that charm quarks participate in coalescence hadronization in the QGP.

Acknowledgments

This work is supported by the grants CZ.02.1.01/0.0/0.0/16_013/0001569, LG15001, LM2015054 (Brookhaven National Laboratory - participation of the Czech Republic) and LM2015058 (Research Infrastructure for Experiments at CERN) of Ministry of Education, Youth and Sports of the Czech Republic.

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