Measurements of open-charm hadrons in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV by the STAR experiment

Jan Vanek[1], for the STAR Collaboration

Nuclear Physics Institute, Czech Academy of Sciences, Řež, Czech Republic
vanek@ujf.cas.cz

Abstract. At RHIC energies, charm quarks are primarily produced at early stages of ultra-relativistic heavy-ion collisions. This makes them an excellent probe of the Quark-Gluon Plasma (QGP) produced in these collisions since they experience the whole evolution of the medium. STAR is able to study the production of charm quarks through direct reconstruction of hadronic decays of open-charm hadrons. This is possible thanks to an excellent vertex resolution provided by the Heavy Flavor Tracker. In these proceedings, we present a selection of the most recent results on open-charm hadron production, in particular the nuclear modification factors of $\mathrm{D}^{\pm}$ and D^0, elliptic and triangular flow of D^0, the $\Lambda_c^{\pm}/\mathrm{D}^0$ yield ratio, and the directed flow of D^0 mesons.

Keywords: Open-charm hadrons, quark-gluon plasma, STAR experiment, Heavy-Flavor Tracker, nuclear modification factor, elliptic flow, directed flow

1 Introduction

One of the main goals of the heavy-ion program at the STAR experiment is to study properties of the Quark-Gluon Plasma (QGP). Charm quarks are an excellent probe of the QGP as they are produced at very early stages of ultra-relativistic heavy-ion collisions and so experience the whole evolution of the hot and dense medium. STAR is able to study production of charm quarks through a precise topological reconstruction of open-charm hadron decays utilizing the Heavy Flavor Tracker (HFT) [1].

Various measurements are used to study interactions of charm quarks with the QGP. In these proceedings, we present a selection of the most recent results on open-charm hadron production from the STAR experiment. In particular, we discuss the nuclear modification factors of $\mathrm{D}^{\pm}$ and D^0 mesons which give access to the charm quark energy loss in the QGP, and also D^0 elliptic (v_2) and triangular flow (v_3) coefficients which can probe the charm quark transport in the QGP. We show the $\Lambda_c^{\pm}/\mathrm{D}^0$ yield ratio as a function of transverse momentum (p_{T}) and collision centrality that help us better understand the charm quark hadronization process in heavy-ion collisions. In addition, we present the rapidity-odd directed flow of D^0 mesons, which can be used to probe the initial tilt of the QGP bulk and effects of the early-time magnetic field.

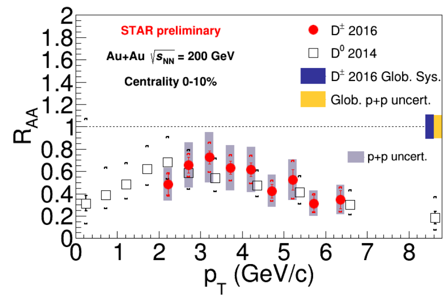

Fig. 1. Nuclear modification factor of D^0 [2] and $D^{\pm}$ mesons as a function of p_T in 0-10% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

2 Results

Figure 1 shows the nuclear modification factors (R_{AA}) of D^0 and $D^{\pm}$ mesons as a function of transverse momentum in 0-10% central Au+Au collisions. Both open-charm mesons show a significant suppression at high p_T which suggest strong interactions of the charm quarks with the QGP. The R_{AA} evolution in low to intermediate p_T region suggests a large collective flow of charm quarks [2] which can also be seen in Figure 2.

Figure 2 demonstrates a test of the Number of Constituent Quarks (NCQ) scaling [3] for elliptic flow (left panel) and triangular flow (right panel) for both D^0 mesons and light-flavor hadrons. The STAR data show that charm quarks acquire similar level of collectivity as the light quarks in the QGP medium.

The presence of the QGP may also influence the charm quark hadronization. In order to study that, STAR has measured the $\Lambda_c^{\pm}/D^0$ yield ratio as a function of p_T (Figure 3, left panel) and number of participants N_{part} (Figure 3, right panel). The ratio shows an enhancement with respect to p+p collisions and PYTHIA calculation, and is reasonably reproduced by models incorporating coalescence hadronization of the charm quarks [6, 7].

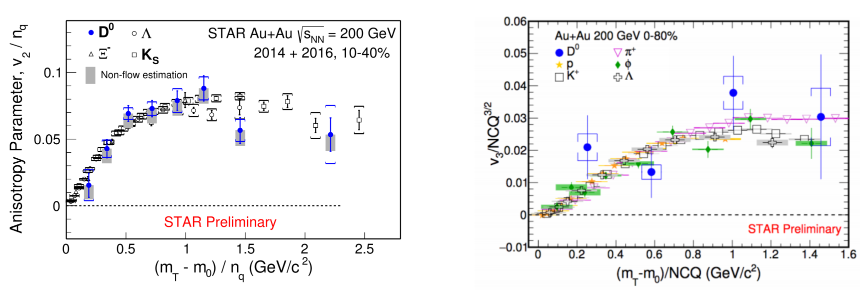

Fig. 2. The NCQ-scaled elliptic **(left)** and triangular **(right)** flow of D^0 mesons and light-flavor hadrons [4] in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

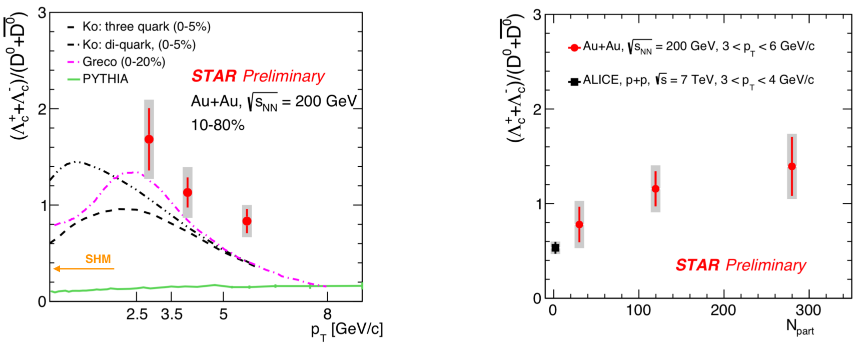

Fig. 3. (left) $\Lambda_c^{\pm}/D^0$ yield ratio as a function of transverse momentum p_T in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The data are compared to PYTHIA, Statistical Hadronization Model [5] and coalescence model calculations [6, 7]. **(right)** $\Lambda_c^{\pm}/D^0$ yield ratio as a function of number of participants N_{part}. The ALICE experiment measurement of the ratio in p+p collisions at $\sqrt{s} = 7$ TeV [8] is shown for comparison.

Theoretical calculations predict that the charm quarks might also be sensitive to the initial tilt of the QGP bulk and the electromagnetic (EM) field induced by the passing spectators [9]. The former leads to a large negative directed flow slope at rapidity (dv_1/dy) of open-charm mesons, and the latter to a negative slope for D^0 and a positive slope for $\overline{D^0}$. When combined, the slope is predicted to be negative for both D^0 and $\overline{D^0}$ but larger for D^0 than for $\overline{D^0}$ in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The STAR result on D^0 and $\overline{D^0}$ v_1 are shown in Figure 4. The current precision of the measurement is not sufficient to conclude on the EM induced splitting, but the dv_1/dy slopes are indeed negative and significantly larger that of light-flavor mesons, as discussed in Ref. [10].

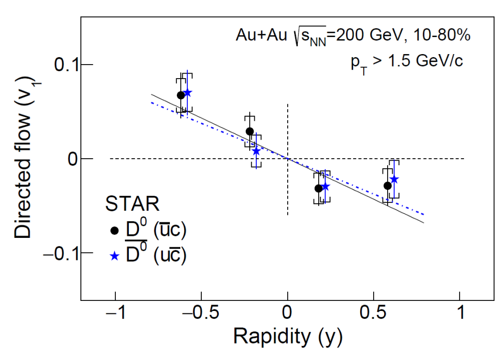

Fig. 4. Directed flow D^0 and $\overline{D^0}$ mesons as a function of rapidity in 10-80% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The solid black and blue dashed lines are fits to the data. Taken from Ref. [10].

3 Summary

The STAR experiment has extensively studied the production of open-charm hadrons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV through a precise topological reconstruction of their hadronic decays, utilizing the HFT. The latest results show that the D^0 and $\mathrm{D}^{\pm}$ mesons are suppressed in central Au+Au collisions, suggesting a substantial energy loss of the charm quarks in the QGP. The charm quarks also exhibit a significant collective motion as suggested by the observed large elliptic and triangular flow of D^0 mesons. The QGP seems to influence the charm quark hadronization. The STAR results on the $\Lambda_{\mathrm{c}}^{\pm}/\mathrm{D}^0$ yield ratio are in qualitative agreement with theoretical models incorporating coalescence hadronization of charm quarks. The measured D^0 $\mathrm{d}v_1/\mathrm{d}y$ slope is qualitatively consistent with hydrodynamical model calculations with tilted QGP bulk [9].

Acknowledgement: These proceedings and presentation are supported by OPVVV grant CZ.02.1.01/0.0/0.0/16_013/0001569 and the project LTT18002 of the Ministry of Education, Youth and Sports of the Czech Republic.

References

1. Beavis, D., et al.: The STAR Heavy-Flavor Tracker, Technical Design Report; 2011. Available online: https://drupal.star.bnl.gov/STAR/starnotes/public/sn0600 (accessed on 6 September 2019).
2. Adam, J., et al. [STAR Collaboration]: Centrality and transverse momentum dependence of D^0-meson production at mid-rapidity in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. *Phys. Rev. C* **99**, 034908, (2019). doi:10.1103/PhysRevC.99.034908
3. S. Afanasiev, et al [PHENIX Collaboration]: Elliptic flow for phi mesons and (anti)deuterons in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. *Phys. Rev. Lett.* **99**, 052301, (2007). doi:10.1103/PhysRevLett.99.052301
4. Abelev, B.I. et al. [STAR Collaboration]: Centrality dependence of charged hadron and strange hadron elliptic flow from $\sqrt{s_{\mathrm{NN}}} = 200$ GeV Au+Au collisions. *Phys. Rev. C* **77**, 054901, (2008). doi:10.1103/PhysRevC.77.054901
5. Andronic, A., et al.: Statistical hadronization of charm in heavy-ion collisions at SPS, RHIC and LHC. *Phys. Lett. B* **571**, 36–44, (2003). doi:10.1016/j.physletb.2003.07.066
6. Oh, Y. et al.: Ratios of heavy baryons to heavy mesons in relativistic nucleus-nucleus collisions. *Phys. Rev. C* **79**, 044905, (2009). doi:10.1103/PhysRevC.79.044905
7. Plumari, S.; Minissale, V.; Das, S.K.; Coci, G.; Greco, V.: Charmed hadrons from coalescence plus fragmentation in relativistic nucleus-nucleus collisions at RHIC and LHC. *Eur. Phys. J. C* **78**, 348, (2018). doi:10.1140/epjc/s10052-018-5828-7
8. Acharya, S.; et al. [The ALICE collaboration]: Λ_c^+ production in pp collisions at $\sqrt{s} = 7$ TeV and in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. *J. High Energ. Phys.* **2018**, 108, (2018). doi:10.1007/JHEP04(2018)108
9. Chatterjee, S.; Bozek, P.: Interplay of drag by hot matter and electromagnetic force on the directed flow of heavy quarks. **2018**, arXiv:1804.04893.
10. Adam, J. et al. [STAR Collaboration]: First observation of the directed flow of D^0 and $\overline{\mathrm{D}^0}$ in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. *Phys. Rev. Lett.* **123**, 162301, (2019). doi:10.1103/PhysRevLett.123.162301