proceedings

MDPI

Proceedings

Production of Open-Charm Hadrons in Au+Au Collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV Mesured by the STAR Experiment †

Jan Vanek

Nuclear Physics Institute, Czech Academy of Sciences, Rez, 250 68, Czech Republic; vanek@ujf.cas.cz; Tel.: +420-266-177-206

† Presented at Hot Quarks 2018—Workshop for young scientists on the physics of ultra-relativistic nucleus-nucleus collisions, Texel, The Netherlands, 7–14 September 2018.

Published: 10 April 2019

check for updates

Abstract: Charm quarks are primarily produced at the early stages of ultra-relativistic heavy-ion collisions and can therefore probe the quark-gluon plasma throughout its whole evolution. Final-state open-charm hadrons are commonly used to experimentally study the charm quark interaction with the medium. Thanks to the excellent secondary vertex resolution provided by the Heavy Flavor Tracker, STAR is able to directly reconstruct $D^{\pm}$, D^0, D_s, and $\Lambda_c^{\pm}$ via their hadronic decay channels. The topological cuts for signal extraction are optimized using supervised machine learning techniques. In these proceedings, we present an overview of recent open charm results from the STAR experiment. The nuclear modification factors of open-charm mesons and $\Lambda_c^{\pm}/D^0$ ratio are shown as functions of transverse momentum and collision centrality.

Keywords: quark-gluon plasma; STAR experiment; heavy-ion collisions; heavy-flavor mesons; nuclear modification factor; baryon/meson ratio

---

1. Introduction

At RHIC energies, charm and bottom quarks are produced predominantly through hard partonic scatterings at the early stage of a heavy-ion collision. Therefore, most open-charm hadrons observed at RHIC come from hadronization of primordial charm quarks or decays of b-hadrons. This makes them an ideal probe of the Quark-Gluon Plasma (QGP) because they experience the entire evolution of the medium. A selection of recent open-charm hadron results from Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, measured by the STAR experiment using data recorded in 2014 and 2016, is presented and discussed in these proceedings.

The secondary vertices of charm hadrons are reconstructed topologically, utilizing the STAR Heavy Flavor Tracker (HFT) [1,2]. The specific decay channels used in the analysis and basic properties of the open-charm hadron decays are summarized in Table 1. These new measurements will provide insights into phenomena, such as the energy loss of partons inside the QGP and the hadronization process.

Table 1. Summary of open-charm hadrons measured at STAR using the HFT. The left column contains decay channels used for the reconstruction, $c\tau$ is the mean lifetime of a given hadron, and BR is the branching ratio. Numbers are taken from Ref. [3].

Decay Channel	$c\tau$ [μm]	BR [%]
$D^+ \to K^- \pi^+ \pi^+$	311.8 ± 2.1	9.46 ± 0.24
$D^0 \to K^- \pi^+$	122.9 ± 0.4	3.93 ± 0.04
$D_s^+ \to \phi\pi^+ \to K^- K^+ \pi^+$	149.9 ± 2.1	2.27 ± 0.08
$\Lambda_c^+ \to K^- \pi^+ p$	59.9 ± 1.8	6.35 ± 0.33

2. Open-Charm Measurements with the HFT

The main sub-systems for reconstruction of open heavy-flavor hadrons in STAR are the Time Projection Chamber (TPC) which is used for momentum determination and for particle identification, the Time Of Flight (TOF) which improves the particle identification, and the HFT which enables precise reconstruction of the decay topology.

To reconstruct the open-charm hadrons, a series of selection criteria has to be applied to the events and tracks first. The specific selection of the topological variables and values of the criteria depend on the open-charm hadron species and its decay channel. After applying all the selection criteria, the open-charm hadron raw yields (Y_{raw}) are extracted from the invariant mass spectrum. The invariant yield is then calculated from Y_{raw} as:

$$\frac{d^2N}{2\pi p_T dp_T dy} = \frac{Y_{\text{raw}}}{2\pi N_{\text{evt}} BR\, p_T \Delta p_T \Delta y \varepsilon(p_T)}, \tag{1}$$

where N_{evt} is number of events, BR is the branching ratio, p_T is the transverse momentum, y is the rapidity and $\varepsilon(p_T)$ is the reconstruction efficiency. The nuclear modification factor (R_{AA}) is subsequently calculated according to formula:

$$R_{AA}(p_T) = \frac{dN^{AA}/dp_T}{\langle N_{\text{coll}}\rangle dN^{pp}/dp_T}, \tag{2}$$

where dN^{AA}/dp_T and dN^{pp}/dp_T are the invariant yields measured in heavy-ion collisions and p+p collisions respectively and $\langle N_{\text{coll}}\rangle$ is the mean number of binary nucleon-nucleon collisions computed from the Glauber model. The results presented in this proceedings use a combined measurement of $D^\star$ and D^0 in p+p collisions at $\sqrt{s} = 200$ GeV measured by the STAR experiment in 2009 [4] as a reference.

Figure 1 shows the nuclear modification factor R_{AA} of D^0 and $D^\pm$ mesons as a function of transverse momentum p_T for 0–10% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. As expected, the level of suppression of D^0 and $D^\pm$ is similar.

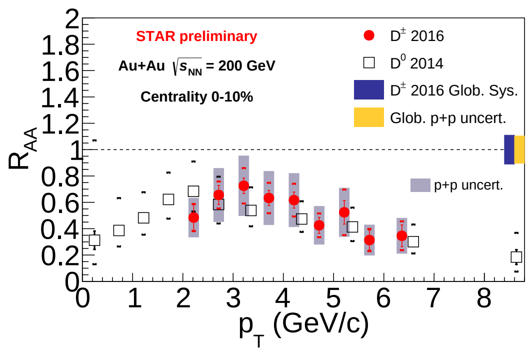

Figure 1. R_{AA} of $D^\pm$ and D^0 mesons as a function p_T in 0–10% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

This result shows that open-charm mesons are significantly suppressed at high p_T, suggesting strong interaction between the charm quarks and the QGP. It is important to note that the Cold Nuclear Matter (CNM) effects may contribute to the suppression as well. Interestingly, the low p_T D^0 mesons also show a suppression. As a result, the integrated R_{AA} of D^0 mesons is below unity which shows that the suppression is likely not only due to the shift in the p_T spectrum, caused by the energy loss in the medium, but also other effects, such as a redistribution of charm quarks among different charm hadrons.

In order to understand the hadronization process in heavy-ion collisions, STAR has measured the D_s/D^0 ratio which is shown in Figure 2. This ratio is larger in Au+Au collisions than predicted by PYTHIA and than that in e+e, p+p and e+p collisions [5]. A better prediction is achieved by the TAMU model [6], but it still underestimates the data. In contrast, the value predicted by the SHM [7] seems to be consistent with the data. This result indicates that the modification of open-charm hadron production in heavy-ion collisions depends on the quark content of the final state hadron.

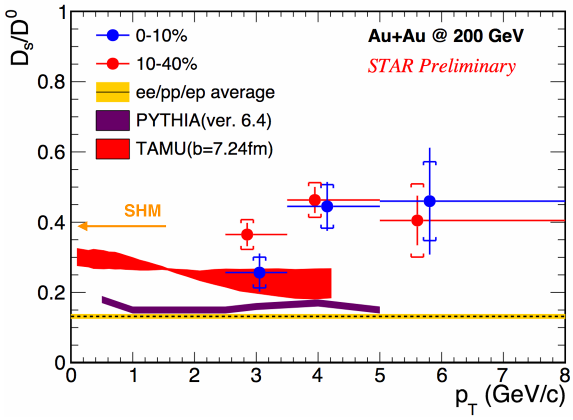

Figure 2. D_s/D^0 ratio as a function of p_T for two centralities. The data is compared to combined e+e, p+p and e+p data [5], PYTHIA, TAMU [6] and SHM [7] models.

For a full understanding of charm production and hadronization in heavy-ion collisions, it is important to study, besides the production of charm mesons, also production of charm baryons. STAR performed the first measurement of Λ_c production in heavy-ion collisions as a functions of collision centrality and p_T. The left panel of Figure 3 shows p_T dependence of the Λ_c/D^0 ratio. PYTHIA and the SHM clearly underestimate the data which indicates significant enhancement of Λ_c production in Au+Au collisions. The coalescence models [8,9] are much closer to the data, but still are not quite able to describe the STAR result, especially at high p_T.

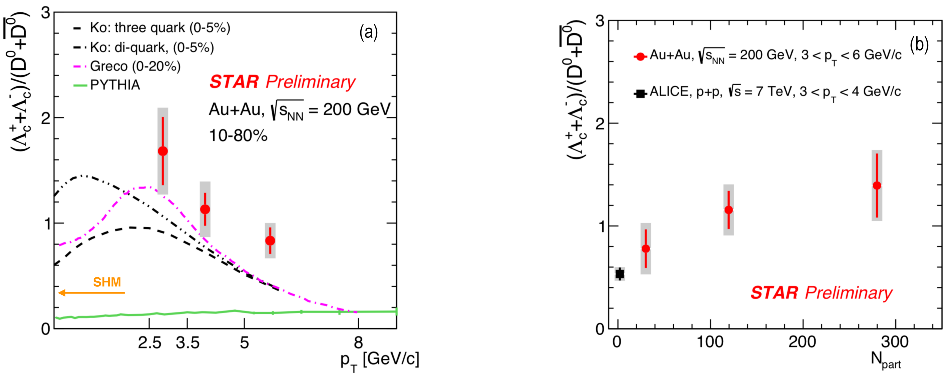

Figure 3. (**a**) The Λ_c/D^0 ratio as a function of p_T for semi-central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The data is compared to coalescence models [8,9], SHM [7] and PYTHIA. (**b**) The Λ_c/D^0 ratio as a function of centrality. The STAR data is compared to ALICE measurement for p+p collisions at $\sqrt{s} = 7$ TeV [10].

It is very important to note here that, according to this measurement, the production of Λ_c is significantly enhanced in heavy-ion collisions with respect to p+p collisions. This, at least partially, explains the significant suppression of open-charm mesons shown in Figure 1. The right panel of Figure 3 shows that the Λ_c/D^0 ratio increases with the collision centrality which suggests that the larger and the more dense the medium is in a heavy-ion collision, the larger the enhancement of the Λ_c production is observed. Finally, the STAR data are also compared to result from p+p collisions at $\sqrt{s} = 7$ TeV measured by ALICE [10]. The value from the p+p collisions is consistent with that in peripheral Au+Au collisions.

3. Summary

The STAR experiment has measured open-charm hadrons through their hadronic decay channels in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Topological reconstruction of secondary decay vertices has been used, utilizing the STAR Heavy Flavor Tracker, which has lead to results with exceptional precision. A significant suppression of D^0 and $D^{\pm}$ mesons is observed in central Au+Au collisions, indicating strong interaction of charm quarks with the QGP. The current STAR data also indicate an enhancement of D_s production in Au+Au collisions with respect to e+e, p+p and p+e collisions. This result will help better understand the hadronization process in heavy-ion collisions. The first measurement of Λ_c baryon production as a function of centrality and p_T in Au+Au collisions is also shown. A significant enhancement of the Λ_c production is observed in central Au+Au collisions, suggesting coalescence hadronization of charm quarks in the QGP.

Funding: This paper and the presentation at HQ2018 are funded by project LTT18002 of the Ministry of Education, Youth and Sport of the Czech Republic and by the Grant Agency of the Czech Technical University in Prague, grant No. SGS16/238/OHK4/3T/14.

Acknowledgments: I would like to thank the organizers for giving me the opportunity to present STAR results at the Hot Quarks 2018 conference.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Beavis, D.; Debbe, R.; Lee, J. H.; LeVine, M. J.; Scheetz, R. A.; Videbaek, F.; Xu, Z.; Bielcik, J.; Krus, M.; Dunkelberger, L.E.; et al. The STAR Heavy Flavor Tracker. In *Technical Design Report*; 2011. Available online: https://drupal.star.bnl.gov/STAR/starnotes/public/sn0600 (accessed on 5 April 2019).
2. Contin, G.; Greiner, L.; Schambach, J.; Szelezniak, M.; Anderssen, E.; Bell, J.; Cepeda, M.; Johnson, T.; Qiu, H.; Ritter, H.-G.; et al. The STAR MAPS-based PiXeL detector. *Nucl. Instrum. Meth. A* **2018**, *907*, 60–80, doi:10.1016/j.nima.2018.03.003.
3. Tanabashi, M.; Hagiwara, K.; Hikasa, K.; Nakamura, K.; Sumino, Y.; Takahashi, F.; Tanaka, J.; Agashe, K.; Aielli, G.; Amsler, C.; et al. Review of Particle Physics. *Phys. Rev. Lett.* **2018**, *98*, 030001, doi:10.1103/PhysRevD.98.030001.
4. Adamczyk, L.; Agakishiev, G.; Aggarwal, M. M.; Ahammed, Z; Alakhverdyants, A. V.; Alekseev, I.; Alford, J.; Anderson, B. D.; Anson, C. D.; Arkhipkin, D.; et al. Measuremets of D^0 and $D^{\star}$ production in p+p collisions at $\sqrt{s} = 200$ GeV. *Phys. Rev. D* **2012**, *86*, 072013, doi:10.1103/PhysRevD.86.072013.
5. Lisovyi, M.; Verbytskyi, A.; Zenaiev, O. Combined analysis of charm-quark fragmentation-function measurements. *Eur. Phys. J. C* **2017**, *76*, 397, doi:10.1140/epjc/s10052-016-4246-y.
6. He, M.; Fries, R.J.; Rapp, R. D_s Meson as a Quantitative Probe of Diffusion and Hadronization in Nuclear Collisions. *Phys. Rev. Lett.* **2013**, *110*, 112301, doi:10.1103/PhysRevLett.110.112301.
7. Andronic, A.; Braun-Munzinger, P.; Redlich, K.; Stachel, J. Statistical hadronization of charm in heavy-ion collisions at SPS, RHIC and LHC. *Phys. Lett. B* **2003**, *571*, 36–44, doi:10.1016/j.physletb.2003.07.066.
8. Oh, Y.; Ko, C.M.; Lee, S.H.; Yasui, S. Ratios of heavy baryons to heavy mesons in relativistic nucleus-nucleus collisions. *Phys. Rev. C* **2009**, *79*, 044905, doi:10.1103/PhysRevC.79.044905.

9. 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* **2018**, *78*, 348, doi:10.1140/epjc/s10052-018-5828-7.
10. Acharya, S.; Acosta, F. T.; Adamová, D.; Adolfsson, J.; Aggarwal, M.M.; Aglieri Rinella, G.; Agnello, M.; Agrawal, N.; Ahammed, Z.; Ahn, S. U.; et al. Λ_c^+ production in pp collisions at $\sqrt{s} = 7$ TeV and in p-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV. *J. High Energ. Phys.* **2018**, *9*, 108, doi:10.1007/JHEP04(2018)108.