EPJ Web of Conferences **171**, 17003 (2018) https://doi.org/10.1051/epjconf/201817117003
*SQM 2017*

# Production of $\mathrm{D}^0$ meson in pp and PbPb Collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with CMS

*Yen-Jie* Lee[1,⋆] on behalf of the CMS Collaboration

[1] *Massachusetts Institute of Technology*

**Abstract.** Heavy flavour mesons are used as powerful tools for the study of the strongly interacting medium in heavy ion collisions as heavy quarks are sensitive to the transport properties of the medium. In these proceedings, $\mathrm{D}^0$ nuclear modification factors, comparing the yields in PbPb and pp collisions, and azimuthal anisotropies in PbPb collisions are reported. Prompt $\mathrm{D}^0$ mesons and their antiparticles have been measured with the CMS detector via the hadronic decay channels $\mathrm{D}^0 \rightarrow \mathrm{K}^-\pi^+$ and $\overline{\mathrm{D}}^0 \rightarrow \mathrm{K}^+\pi^-$ in PbPb and pp collisions at a centre-of-mass energy of 5.02 TeV. Nonprompt $\mathrm{D}^0$ from b quark decays are subtracted. The $\mathrm{D}^0$ results are compared to inclusive charged particles, nonprompt $\mathrm{J}/\psi$ mesons from b decays and $\mathrm{B}^+$mesons in order to reveal possible meson mass dependence of the observables.

Heavy quarks are effective probes to study the properties of the deconfined medium created in heavy ion collisions. These quarks are mostly produced in primary hard QCD scatterings with a production timescale that is shorter than the formation time of the Quark Gluon Plasma (QGP) [1, 2]. Therefore, they carry information about the early stages of the QGP. During their propagation through the medium, heavy quarks lose energy via radiative and collisional interactions with the medium constituents. Quarks are expected to lose less energy than gluons as a consequence of their smaller colour factor. In addition, the so-called “dead-cone effect" is expected to reduce small-angle gluon radiation of heavy quarks when compared to both gluons and light quarks [3–5]. Energy loss can be studied using the nuclear modification factor ($R_{\mathrm{AA}}$), defined as the ratio of the PbPb yield to the pp cross-section scaled by the nuclear overlap function [6]. Moreover, the azimuthal anisotropy of produced $\mathrm{D}^0$ mesons can be characterized by the Fourier coefficients $v_n$ in the azimuthal angle ($\phi$) distribution of the hadron yield, $\mathrm{d}N/\mathrm{d}\phi \propto 1 + 2\sum_n v_n \cos[n(\phi - \Psi_n)]$, where $\Psi_n$ is the azimuthal angle of the direction of the maximum particle density of the $n^{th}$ harmonic in the transverse plane [7]. At low transverse momentum ($p_{\mathrm{T}}$), the charm hadron $v_n$ coefficient can help quantify the extent to which charm quarks flow with the medium, which is a good measure of their interaction strength. The measurements of $R_{\mathrm{AA}}$ and $v_n$ can also help explore the coalescence production mechanism for charm hadrons where charm quarks recombine with light quarks from the medium, which could also lead to positive charm hadron $v_n$ [8, 9]. At high $p_{\mathrm{T}}$, the charm hadron $v_n$ coefficient can constrain the path length dependence of charm quark energy loss [10, 11], complementary to the $R_{\mathrm{AA}}$ measurements. Precise measurements of the $R_{\mathrm{AA}}$ and the azimithal anisotropy of particles containing both light and heavy quarks can thus provide important tests of QCD predictions at extreme densities and temperatures. In these proceedings, the production of prompt $\mathrm{D}^0$ mesons in PbPb collisions at 5.02 TeV is measured for the first time

⋆e-mail: yenjie@mit.edu

up to a $p_{\mathrm{T}}$ of 100 GeV/$c$, allowing one to study the properties of the in-medium energy loss in a new kinematic regime. The $\mathrm{D}^0$ meson and its antiparticle are studied in the central rapidity region ($|y| < 1$) of the CMS detector via the hadronic decay channels $\mathrm{D}^0 \to \mathrm{K}^-\pi^+$ and $\overline{\mathrm{D}}^0 \to \mathrm{K}^+\pi^-$.

A detailed description of the CMS experiment can be found in Ref. [12]. The $\mathrm{D}^0$ candidates are reconstructed by combining pairs of oppositely charged particle tracks with an invariant mass within 0.2 GeV/$c^2$ of the world-average $\mathrm{D}^0$ mass [13]. Each track is required to have $p_{\mathrm{T}} > 1$ GeV/$c$ in order to reduce the combinatorial background. For high-$p_{\mathrm{T}}$ $\mathrm{D}^0$ mesons (above 20 GeV/$c$) in PbPb data, the single track cut is raised to $p_{\mathrm{T}} > 8.5$ GeV/$c$ to account for the selection ($p_{\mathrm{T}} > 8$ GeV/$c$) performed with a software-based high level trigger. All tracks are also required to be within $|\eta| < 1.5$. For each pair of selected tracks, two $\mathrm{D}^0$ candidates are created by assuming that one of the particles has the mass of the pion while the other has the mass of the kaon, and vice-versa. The $\mathrm{D}^0$ mesons are required to be within $|y| < 1$, optimized in conjunction to the track pseudorapidity selection to give the best signal to background ratio over the whole range of $\mathrm{D}^0$ $p_{\mathrm{T}}$ studied. In order to further reduce the combinatorial background, the $\mathrm{D}^0$ candidates are selected based on three topological criteria: on the three-dimensional (3D) decay length $L_{\mathrm{xyz}}$ normalized to its uncertainty, on the pointing angle $\theta_{\mathrm{p}}$ (defined as the angle between the total momentum vector of the tracks and the vector connecting the primary and the secondary vertices), and on the $\chi^2$ probability of the $\mathrm{D}^0$ vertex fit. Details of the $\mathrm{D}^0$ selection criteria and the signal extraction procedure for the $R_{\mathrm{AA}}$ and $v_n$ analyses are documented in Refs. [14, 15].

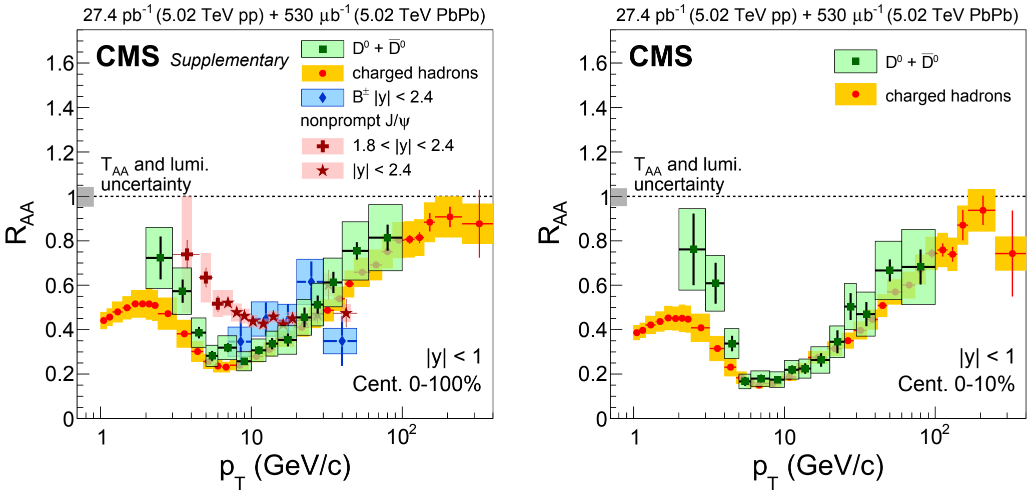


**Figure 1.** (Left) Nuclear modification factor $R_{\mathrm{AA}}$ as a function of $p_{\mathrm{T}}$ in the centrality range 0–100% (green squares) compared to the $R_{\mathrm{AA}}$ of charged particles (red circles) [16], $\mathrm{B}^{\pm}$ mesons (blue triangles) [17] and to the preliminary results of $R_{\mathrm{AA}}$ of nonprompt $\mathrm{J}/\psi$ meson (purple crosses and stars) [18] in the same centrality range. (Right) Nuclear modification factor $R_{\mathrm{AA}}$ as a function of $p_{\mathrm{T}}$ in the centrality range 0–10% (green squares) compared to the $R_{\mathrm{AA}}$ of charged particles (red circles) [16] in the same centrality range.

Figure 1 shows the $\mathrm{D}^0$ $R_{\mathrm{AA}}$ as a function of $p_{\mathrm{T}}$ in two centrality classes. The $\mathrm{D}^0$ meson yield is found to be strongly suppressed in PbPb collisions when compared to the measured pp reference data scaled by the number of binary nucleon-nucleon collisions. These measurements are consistent with the $R_{\mathrm{AA}}$ of charged hadrons in both centrality intervals for $p_{\mathrm{T}} > 4$ GeV/$c$. A hint of a smaller suppression of $D^0$ $R_{AA}$ with respect to charged particle $R_{AA}$ is observed for $p_T < 4$ GeV/$c$. The $D^0$ $R_{AA}$ was found to be compatible with the $B^{\pm}$ $R_{AA}$ in the intermediate $p_T$ region and significantly lower than the nonprompt $J/\psi$ meson $R_{AA}$ for $p_T < 10$ GeV/$c$.

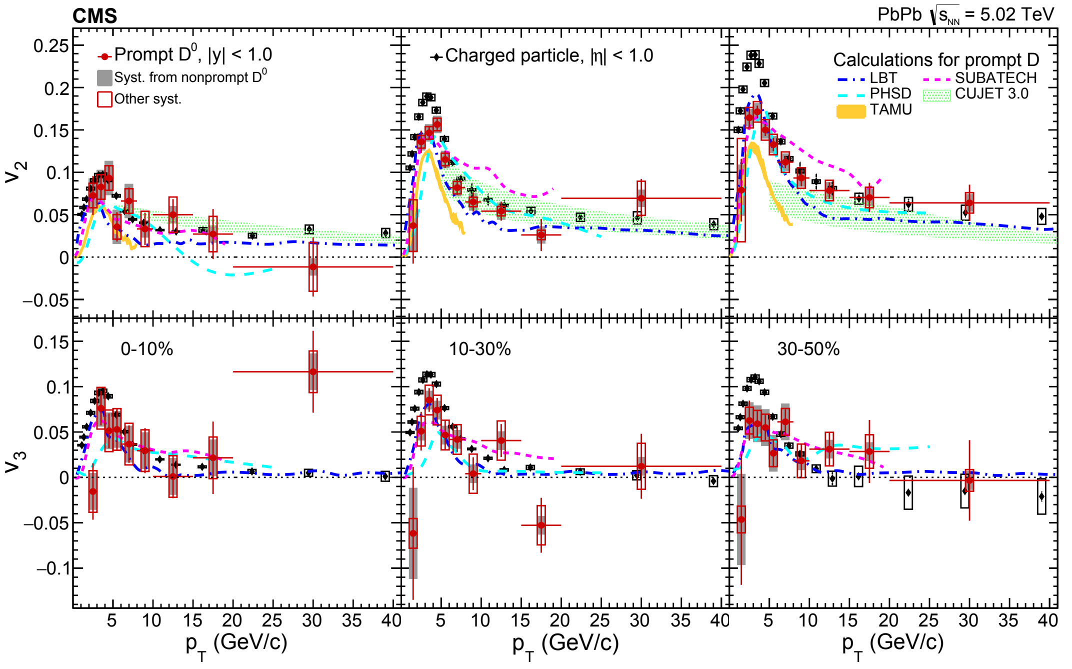


**Figure 2.** Prompt $D^0$ meson $v_2$ (upper) and $v_3$ (lower) coefficients at midrapidity ($|y| < 1.0$) for the centrality classes 0–10% (left), 10–30% (middle), and 30–50% (right). The vertical bars represent statistical uncertainties, grey bands represent systematic uncertainties from nonprompt $D^0$ mesons and open boxes represent other systematic uncertainties. The measured $v_n$ coefficient of charged particles at midpseudorapidity ($|\eta| < 1.0$) [19] and theoretical calculations for prompt D meson $v_n$ coefficient [20–24] are also plotted for comparison.

Figure 2 shows the prompt $D^0$ meson $v_2$ and $v_3$ coefficients at midrapidity ($|y| < 1.0$) in different centrality classes and compares them to those of charged particles (dominated by light flavor hadrons) at midpseudorapidity ($|\eta| < 1.0$) [19]. The $D^0$ meson $v_2$ and $v_3$ coefficients increase with $p_T$ to significant positive values in the low-$p_T$ region, and then decrease for higher $p_T$. Compared to those of charged particles, the $D^0$ meson $v_2$ and $v_3$ coefficients exhibit a similar $p_T$ dependence. As has been observed for charged particles, the $D^0$ meson $v_2$ coefficient increases with decreasing centrality in the 0–50% centrality range, while the $v_3$ coefficient shows little centrality dependence. For $p_T < 6$ GeV/$c$, the magnitudes of $D^0$ meson $v_2$ and $v_3$ coefficients are smaller than those for charged particles in the centrality classes 10–30% and 30–50%. The comparison between the $D^0$ meson results and theoretical calculations in this low-$p_T$ region suggests a collective motion of charm quarks. For $p_T >$ 6 GeV/$c$, the $D^0$ meson $v_2$ values remain positive, suggesting a path length dependence of the charm quark energy loss; the $D^0$ meson $v_3$ precision is limited by the available data. The $D^0$ meson $v_2$ values are consistent with those of charged particles, suggesting that the path length dependence of charm quark energy loss is similar to that of light quarks.

In summary, the $D^0$ meson nuclear modification factor and azimuthal anisotropy coefficients in the central rapidity region ($|y| < 1$) at $\sqrt{s_{NN}} = 5.02$ TeV from CMS are presented. The results are compared to those from inclusive charged particles, nonprompt $J/\psi$ and $B^+$ mesons. Those high precision $D^0$ $R_{AA}$, $v_2$ and $v_3$ data provide new constraints on models of the interactions between charm quarks and the quark-gluon plasma, and the charm quark energy loss mechanisms.

## References

[1] P. Braun-Munzinger, J. Phys. G **34**, S471 (2007), nucl-th/0701093
[2] F.M. Liu, S.X. Liu, Phys. Rev. C **89**, 034906 (2014), 1212.6587
[3] Y.L. Dokshitzer, D.E. Kharzeev, Phys. Lett. B **519**, 199 (2001), hep-ph/0106202
[4] N. Armesto, C.A. Salgado, U.A. Wiedemann, Phys. Rev. D **69**, 114003 (2004), hep-ph/0312106
[5] A. Andronic et al., Eur. Phys. J. C **76**, 107 (2016), 1506.03981
[6] M.L. Miller, K. Reygers, S.J. Sanders, P. Steinberg, Ann. Rev. Nucl. Part. Sci. **57**, 205 (2007), nucl-ex/0701025
[7] A.M. Poskanzer, S.A. Voloshin, Phys. Rev. C **58**, 1671 (1998), nucl-ex/9805001
[8] D. Molnar, S.A. Voloshin, Phys. Rev. Lett. **91**, 092301 (2003), nucl-th/0302014
[9] V. Greco, C.M. Ko, P. Levai, Phys. Rev. Lett. **90**, 202302 (2003), nucl-th/0301093
[10] M. Gyulassy, I. Vitev, X.N. Wang, Phys. Rev. Lett. **86**, 2537 (2001), nucl-th/0012092
[11] E.V. Shuryak, Phys. Rev. C **66**, 027902 (2002), nucl-th/0112042
[12] S. Chatrchyan et al. (CMS), JINST **3**, S08004 (2008)
[13] Particle Data Group, C. Patrignani et al., Chin. Phys. C **40**, 100001 (2016)
[14] A.M. Sirunyan et al. (CMS) (2017), 1708.04962
[15] A.M. Sirunyan et al. (CMS) (2017), 1708.03497
[16] V. Khachatryan et al. (CMS), JHEP **04**, 039 (2017), 1611.01664
[17] A.M. Sirunyan et al. (CMS), Phys. Rev. Lett. **119**, 152301 (2017), 1705.04727
[18] CMS Collaboration (CMS), CMS Physics Analysis Summary CMS-PAS-HIN-16-025 (2016), https://cds.cern.ch/record/2235781
[19] A.M. Sirunyan et al. (CMS) (2017), 1702.00630
[20] S. Cao, T. Luo, G.Y. Qin, X.N. Wang, Phys. Rev. C **94**, 014909 (2016), 1605.06447
[21] M. Nahrgang, J. Aichelin, S. Bass, P.B. Gossiaux, K. Werner, Phys. Rev. C **91**, 014904 (2015), 1410.5396
[22] T. Song, H. Berrehrah, D. Cabrera, W. Cassing, E. Bratkovskaya, Phys. Rev. C **93**, 034906 (2016), 1512.00891
[23] M. He, R.J. Fries, R. Rapp, Phys. Lett. B **735**, 445 (2014), 1401.3817
[24] J. Xu, J. Liao, M. Gyulassy, JHEP **02**, 169 (2016), 1508.00552