Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 982 (2019) 579–582

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Measurements of heavy-flavour correlations and jets with ALICE at the LHC

Barbara Trzeciak[a], for the ALICE Collaboration

[a]*Institute for Subatomic Physics*
Faculty of Science, Utrecht University

Abstract

In this work, the latest heavy-flavour correlation and jet measurements at mid-rapidity with the ALICE detector in pp, p–Pb and Pb–Pb collisions from the LHC Run 2 are reported. In particular, the results of azimuthal correlation measurements of D mesons with charged particles in pp collisions at $\sqrt{s}$ = 13 TeV and in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV are presented. Studies on the centrality-dependent azimuthal correlations of heavy-flavour hadron decay electrons with charged particles in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV are shown. In addition, measurements of D-meson tagged jet production in pp collisions at $\sqrt{s}$ = 7 TeV and in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV are presented, including studies in pp collisions of the jet momentum fraction carried by the D meson. A first result on the D-meson tagged jet nuclear modification factor in central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV is also reported.

Keywords: Quark-Gluon Plasma, Relativistic heavy-ion collisions, Open heavy-flavour, D mesons, Jets, Correlations

1. Introduction

Heavy quarks (charm and beauty) are produced in hard parton scatterings in the early stages of hadronic collisions. Therefore, they are ideal probes to investigate the properties of the Quark–Gluon Plasma (QGP) produced in ultra-relativistic heavy-ion collisions. The study of angular correlations between heavy-flavour particles and charged particles allows us to characterise the heavy-quark fragmentation process and its possible modification in a hot nuclear matter environment. The measurement of heavy-flavour jets gives more direct access to the initial parton kinematics and can provide further constraints for heavy-quark energy loss models, in particular adding information on how the radiated energy is dissipated in the medium. It can provide information on the possible flavour dependence of jet quenching in the medium.

Studies in pp collisions are mandatory to characterise heavy-quark production and fragmentation in vacuum, constituting the necessary reference for interpreting heavy-ion collision results. Differences between results from pp and p–Pb collisions can give insight on how the heavy-quark production and hadronisation into jets are affected by cold nuclear matter effects.

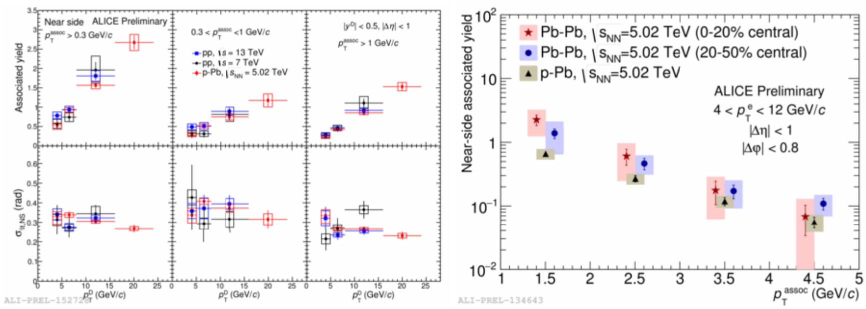
Email address: barbara.antonina.trzeciak@cern.ch (Barbara Trzeciak)

https://doi.org/10.1016/j.nuclphysa.2018.10.085

2. Results

2.1. Azimuthal correlations of D mesons with charged particles

Measurements of azimuthal correlations of prompt D mesons (average of D^0, D^+, D^{*+} mesons) with charged particles in the event were performed by ALICE in pp collisions at $\sqrt{s}$ = 7 TeV [1] and $\sqrt{s}$ = 13 TeV in the D-meson rapidity interval $|y^D| < 0.5$, and in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV in -0.96 $< y^{D}_{cms} <$ 0.04. In order to study the properties of the measured correlations, the azimuthal-correlation distributions, $\Delta\varphi$ between the charged particles and the D meson ($\Delta\varphi = |\varphi_{ch} - \varphi_D|$ within $|\Delta\eta| < 1$), are fitted with a function composed of two Gaussian terms to describe the near- and away-side peaks, induced by the jet containing the D meson and the recoiling jet, and a constant term to describe the pedestal of the distribution, determined mainly by correlations with particles from the underlying event. The associated-particle yields and the widths ($\sigma_{fit,NS}$) of the near-side peak ($\Delta\varphi \approx 0$) are shown in Fig. 1(a), as a function of the D-meson transverse momentum p_T for different associated particle p_T (p_T^{assoc}) intervals. The results in pp collisions for the two energies and in p–Pb collisions are compatible within the uncertainties. Also, a qualitative agreement with Monte Carlo PYTHIA6 tunes [2], PYTHIA8 [3] and POWHEG+PYTHIA6 [4, 5] simulations is found in most of the studied kinematic ranges, as presented in Fig. 2(a) and in [1, 6]. The correlation distributions in p–Pb collisions were also studied as a function of the event multiplicity, in three centrality classes defined by the energy deposited in the ZNA neutron calorimeter [7]: 0–20, 20–60 and 60–100%. No modification of the near-side peak properties is found within the current uncertainties.



(a) (b)

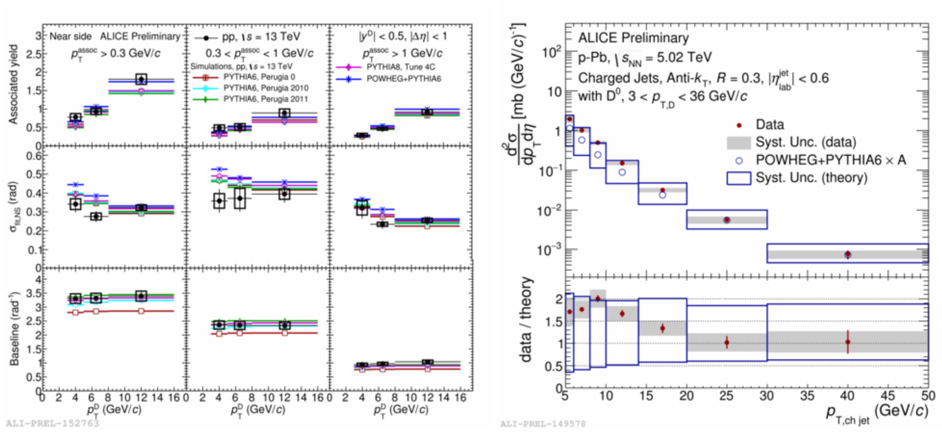
Fig. 1. (a) Near-side associated yields and widths extracted from D-h correlations in pp collisions at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 7 TeV and p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV as a function of D-meson p_T in different p_T^{assoc} ranges. (b) Near-side associated yields extracted from e^{HF}-h correlations in p–Pb and 0–20%, 20–50% central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV as a function of p_T^{assoc} and for $4 < p_T^e < 12$ GeV/c.

2.2. Azimuthal correlations of heavy-flavour hadron decay electrons with charged particles

The ALICE collaboration also measured two-particle correlations between heavy-flavour hadron decay electrons (e^{HF}) and charged particles in p–Pb and Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. The near-side associated yields are extracted in different p_T^{assoc} ranges and for an electron p_T in the interval of $4 < p_T <$ 12 GeV/c. The results in p–Pb, in central (0–20%) and semi-central (20–50%) Pb–Pb collisions, presented in Fig. 1(b), are consistent with each other, with a hint of an enhancement in the central Pb–Pb collisions at low p_T^{assoc}. In addition, studies in high-multiplicity p–Pb collisions show evidence of a positive elliptic flow (v_2) of heavy-flavour electrons, with a significance of more than 5σ for $1.5 < p_T < 4$ GeV/c [8, 9] .

2.3. D-meson tagged jets

D-meson tagged charged jets are reconstructed with the FastJet [10] anti-k_T algorithm [11] using charged-particle tracks and requiring the presence of a D meson among the jet constituents. In addition, in p–Pb and Pb–Pb measurements the background coming from the underlying event is subtracted on a jet-by-jet basis prior to unfolding [12]. Mid-rapidity p_T-differential production cross-sections was measured in pp collisions at $\sqrt{s}$ = 7 TeV [6] and in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV using prompt D^0 and D^{*+} mesons as the tagged particle, respectively. The covered charged jet transverse momentum $p_{T,ch\ jet}$ range starts as low as $p_{T,ch\ jet}$ = 5 GeV/c and is up to $p_{T,ch\ jet}$ = 30 GeV/c, with the jet resolution parameter R = 0.4 and a



(a) (b)

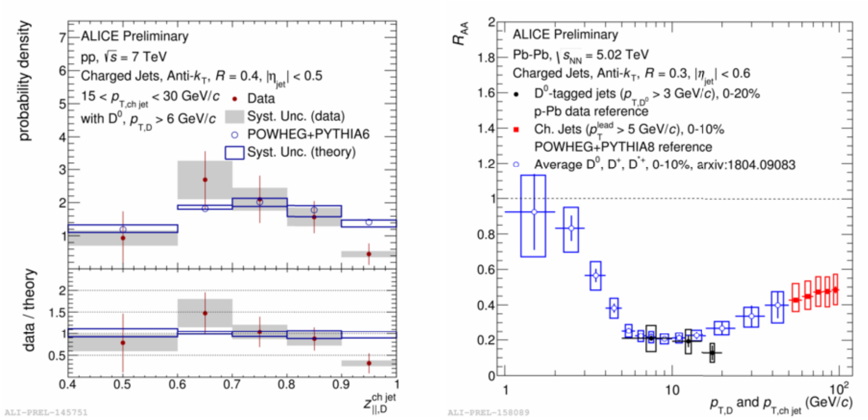
Fig. 2. (a) Near-side associated yields, widths and beseline level extracted from D-h correlations in pp collisions at $\sqrt{s}$ = 13 TeV compared to PYTHIA6, PYTHIA8 and POWHEG+PYTHIA6 predictions. (b) $p_{\rm T}$-differential production cross-section of $\rm D^0$-meson tagged charged jets in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV compared to POWHEG+PYTHIA6 predictions.

requirement of the D-meson transverse momentum $p_{\rm T,D} > 3$ GeV/c. Figure 2(b) presents a new measurement of the $\rm D^0$-tagged jet $p_{\rm T}$-differential cross-section in p–Pb collisions using $R = 0.3$ with a $p_{\rm T,ch\ jet}$ reach extended up to $p_{\rm T,ch\ jet} = 50$ GeV/c. In order to characterise the heavy quark production and fragmentation in more detail, the distribution of the jet momentum fraction carried by $\rm D^0$ meson in the direction of the jet axis $z^{\rm ch\ jet}_{||,D} = \frac{\vec{p}_{\rm ch\ jet}\cdot\vec{p}_{\rm D}}{\vec{p}_{\rm ch\ jet}\cdot\vec{p}_{\rm ch\ jet}}$ was extracted in pp collisions in two jet $p_{\rm T}$ ranges: $5 < p_{\rm T,ch\ jet} < 15$ GeV/c and $15 < p_{\rm T,ch\ jet} < 30$ GeV/c. The distributions are then normalised to a probability density distribution as shown in Fig. 3(a). Both the $z^{\rm ch\ jet}_{||,D}$ and the $p_{\rm T}$-differential cross-section measurements in pp and p–Pb collisions are well described by the Next-to-Leading-Order pQCD calculations of POWHEG coupled with PYTHIA6 shower MC [2, 4, 5].

The p–Pb $\rm D^0$-jet $p_{\rm T}$-differential cross-section is used as a baseline for the measurement of the nuclear modification factor in 0–20% central Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. The Pb–Pb measurement follows the p–Pb analysis technique, with $R = 0.3$ and $p_{\rm T,D} > 3$ GeV/c, which allowed us to obtain a $\rm D^0$-tagged jet $p_{\rm T}$ spectrum in $5 < p_{\rm T,ch\ jet} < 20$ GeV/c. For every signal jet reconstructed with the anti-$k_{\rm T}$ algorithm, the background density scaled by the area of the reconstructed signal jet was subtracted from the reconstructed transverse momentum of the signal jet. The underlying background momentum density was estimated event-by-event using the median of $p^{\rm raw}_{\rm T,ch\ jet}/A_{\rm jet}$, where $p^{\rm raw}_{\rm T,ch\ jet}$ is uncorrected $p_{\rm T,ch\ jet}$ and $A_{\rm jet}$ is the area of jets reconstructed with the $k_{\rm T}$ algorithm. The $p^{\rm raw}_{\rm T,ch\ jet}$ spectrum was then unfolded for the detector response and the background fluctuations in the underlying event extracted using the Random Cone method [13]. The fake jet rejection is greatly improved in this analysis thanks to the jet tagging with an identified D meson. Furthermore, a stability of the unfolding procedure, especially at low $p_{\rm T,ch\ jet}$, was confirmed using a Mone-Carlo closure test. Figure 3(b) shows the nuclear modification factor, $R_{\rm AA}$, for the $\rm D^0$-tagged jets. A strong suppression, similar to the prompt D-meson one [14] is observed, with a hint of a lower $R_{\rm AA}$ compared with the inclusive charged jet measurement at higher $p_{\rm T,ch\ jet}$.

3. Summary

In this contribution, measurements on azimuthal correlations of D mesons with charged particles in pp and p–Pb collisions are reported. The near-side observables are compatible with Monte Carlo predictions. The results in p–Pb collisions suggest that the modification of jets from charm is not significantly affected by the cold nuclear matter effects as well as by possible final-state effects. Predictions from POWHEG+PYTHIA6 simulations, including nuclear shadowing effects for the nucleon PDFs, are also in agreement with the measurements. In the analysis of the azimuthal correlations of heavy-flavour hadron



(a) (b)

Fig. 3. (a) Probability density distribution of the jet momentum fraction, $z_{||,D}^{\text{ch jet}}$, carried by the D^0 mesons in the direction of the jet axis for D^0-meson tagged jets in pp collisions at $\sqrt{s} = 7$ TeV with $15 < p_{\text{T,ch jet}} < 30$ GeV/c compared to POWHEG+PYTHIA6 predictions. (b) Nuclear modification factor, R_{AA}, for D^0-meson tagged jets in 0–20% central Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV.

decay electrons with charged particles a hint of near-side yield enhancement in central Pb–Pb collisions is observed. The p_{T}-differential production cross-sections of D-meson tagged charged jets were measured in pp and p–Pb collisions, and the jet momentum fraction carried by the D meson was extracted in pp collisions in two $p_{\text{T,ch jet}}$ ranges. The measurements are in agreement with POWHEG+PYTHIA6 predictions. Also, a first measurement of the D-meson tagged jet R_{AA} in Pb–Pb collisions is presented. A strong suppression in $5 < p_{\text{T,ch jet}} < 20$ GeV/c is observed in the 0–20% central collisions. A comparison to a theory prediction is needed for further conclusions. The precision of the measurement and the $p_{\text{T,ch jet}}$ reach will be greatly improved with the upcoming 2018 Pb–Pb run and LHC Run 3 and 4, allowing us to complement the studies with more differential analyses.

References

[1] J. Adam, et al., Measurement of azimuthal correlations of D mesons and charged particles in pp collisions at $\sqrt{s} = 7$ TeV and p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV, Eur. Phys. J. C77 (4) (2017) 245. arXiv:1605.06963, doi:10.1140/epjc/s10052-017-4779-8.

[2] T. Sjostrand, S. Mrenna, P. Z. Skands, PYTHIA 6.4 Physics and Manual, JHEP 05 (2006) 026. arXiv:hep-ph/0603175, doi:10.1088/1126-6708/2006/05/026.

[3] T. Sjostrand, S. Mrenna, P. Z. Skands, A Brief Introduction to PYTHIA 8.1, Comput. Phys. Commun. 178 (2008) 852–867. arXiv:0710.3820, doi:10.1016/j.cpc.2008.01.036.

[4] P. Nason, A New method for combining NLO QCD with shower Monte Carlo algorithms, JHEP 11 (2004) 040. arXiv:hep-ph/0409146, doi:10.1088/1126-6708/2004/11/040.

[5] S. Frixione, P. Nason, C. Oleari, Matching NLO QCD computations with Parton Shower simulations: the POWHEG method, JHEP 11 (2007) 070. arXiv:0709.2092, doi:10.1088/1126-6708/2007/11/070.

[6] S. Sakai, Measurement of heavy-flavour production, correlations and jets with ALICE, in: European Physical Journal Web of Conferences, Vol. 171 of European Physical Journal Web of Conferences, 2018, p. 18008. doi:10.1051/epjconf/201817118008.

[7] J. Adam, et al., Centrality dependence of particle production in p-Pb collisions at $\sqrt{s_{\text{NN}}}$= 5.02 TeV, Phys. Rev. C91 (6) (2015) 064905. arXiv:1412.6828, doi:10.1103/PhysRevC.91.064905.

[8] S. Acharya, et al., Azimuthal anisotropy of heavy-flavour decay electrons in p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV, arXiv:1805.04367.

[9] H. J. C. Zanoli, Open heavy-flavour production and elliptic flow in p-Pb collisions at the LHC with ALICE, These proceedings.

[10] M. Cacciari, G. P. Salam, G. Soyez, FastJet User Manual, Eur. Phys. J. C72 (2012) 1896. arXiv:1111.6097, doi:10.1140/epjc/s10052-012-1896-2.

[11] M. Cacciari, G. P. Salam, G. Soyez, The Anti-k(t) jet clustering algorithm, JHEP 04 (2008) 063. arXiv:0802.1189, doi:10.1088/1126-6708/2008/04/063.

[12] J. Adam, et al., Measurement of charged jet production cross sections and nuclear modification in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, Phys. Lett. B749 (2015) 68–81. arXiv:1503.00681, doi:10.1016/j.physletb.2015.07.054.

[13] B. Abelev, et al., Measurement of Event Background Fluctuations for Charged Particle Jet Reconstruction in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, JHEP 03 (2012) 053. arXiv:1201.2423, doi:10.1007/JHEP03(2012)053.

[14] S. Acharya, et al., Measurement of D^0, D^+, D^{*+} and D_s^+ production in Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV, arXiv:1804.09083.