D meson nuclear modification factors in Pb–Pb collisions at $\sqrt{s}_{\rm NN} = 2.76$ TeV, measured with the ALICE detector

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Abstract. The ALICE experiment has measured the D meson production in pp and Pb-Pb collisions at the LHC at $\sqrt{s} = 7$ and 2.76 TeV and $\sqrt{s_{NN}} = 2.76$ TeV respectively, via the exclusive reconstruction of hadronic decay channels. The analyses of the $\rm D^0 \rightarrow K^-\pi^+$ and $\rm D^+ \rightarrow K^-\pi^+\pi^+$ channels will be described and the preliminary results for the $\rm D^0$ and $\rm D^+$ nuclear modification factor will be presented.

1. Introduction

The comparison of heavy flavour production in proton-proton and heavy-ion collisions allows to probe the properties of the high-density QCD medium formed in the latter and to study the mechanism of in-medium partonic energy loss [1]. A sensitive observable is the nuclear modification factor, defined, for a particle species h, as $R^h_{\rm AA}(p_{\rm t}) = \frac{{\rm d}N^h_{\rm AA}/{\rm d}p_{\rm t}}{\langle T_{\rm AA}\rangle \times {\rm d}\sigma^h_{\rm pp}/{\rm d}p_{\rm t}}$, where $N^h_{\rm AA}$ is the normalized yield measured in heavy-ion collisions, $\langle T_{\rm AA}\rangle$ is the average nuclear overlap function calculated with the Glauber model in the considered centrality range, and $\sigma^h_{\rm pp}$ is the production cross-section in pp collisions. For hard processes, in the absence of any medium and cold nuclear matter effect, $R_{\rm AA} = 1$ is expected. By comparing the nuclear modification factors of charged pions ($R^{\pi^\pm}_{\rm AA}$), mostly originating from gluon fragmentation, with that of hadrons with charm ($R^{\rm D}_{\rm AA}$) and beauty ($R^{\rm B}_{\rm AA}$) the dependence of the energy loss on the parton nature (quark/gluon) and mass can be investigated. A mass ordering pattern $R^{\pi^\pm}_{\rm AA}(p_{\rm t}) \lesssim R^{\rm D}_{\rm AA}(p_{\rm t}) \lesssim R^{\rm B}_{\rm AA}(p_{\rm t})$ has been predicted [2]. In these proceedings the measurement of the $\rm D^0$ and $\rm D^+$ $R_{\rm AA}$ in Pb–Pb collisions at the LHC is presented. More information on the ALICE detector can be found in [3, 4]; the procedure to determine the collision centrality is described in [5].

2. Measurement of D meson production with the ALICE detector

The production of $\rm D^0$ and $\rm D^+$ ($c\tau \approx 123$ and 312 μm respectively [6]) was measured in pp and Pb–Pb collisions at central rapidity ($|y| < 0.5$) via the exclusive reconstruction of the decays $D^0 \to K^-\pi^+$ (with branching ratio, BR=3.89±0.05% [6]) and $D^+ \to K^-\pi^+\pi^+$ (BR=9.4 ± 0.4% [6]). The analysis strategy for the extraction of the D^0 and D^+ signals out of the large combinatorial background from uncorrelated tracks is based on the reconstruction and selection of secondary vertex topologies with significant separation (typically a few hundred micrometer) from the primary vertex. The Time Projection Chamber (TPC) and the Inner Tracking System (ITS) detectors provide a spatial resolution on the track position in the vicinity of the primary vertex of the order of few tens of microns at sufficiently high p_t [7]. Tracks displaced from the primary vertex are selected to reconstruct D meson candidates. Good alignment between the reconstructed meson momentum and the flight direction between the primary and secondary vertex is also required. The identification of the charged kaon in the TPC and Time Of Flight detectors provides additional background rejection. A particle identification strategy that preserves most of the D meson signal was adopted. Similar analyses were performed on pp and Pb–Pb data, with a tighter selection in the latter case, dictated by the higher combinatorial background. To extract the signal, a fit to the invariant mass distribution is performed, using a Gaussian function for the signal peak and an exponential function for the background. Figure 1 (left) shows the invariant mass distribution of D^0 candidates for $p_t > 2$ GeV/c, obtained from the analysis of $\approx 3 \times 10^6$ Pb–Pb events in the $0-20$% centrality range. The 'raw' signal is corrected for acceptance and efficiency using Monte Carlo simulations based on Pythia (Perugia-0 tuning) and HIJING event generators. The contribution of D mesons from B decays was evaluated relying on the FONLL prediction, which describes well bottom production at the Tevatron [8] and at the LHC [9, 10]. In the Pb–Pb case, the FONLL prediction of secondary D mesons production in pp collisions is multiplied by $\langle N_{\rm coll}\rangle \times R_{\rm AA}^{\rm B}$, where the hypothesis on the B meson $R_{\rm AA}$ encodes all potential nuclear and medium effects affecting B production. The systematic error due to the FONLL theoretical uncertainty on beauty prediction was estimated from the spread of the results recovered using the minimum and maximum predictions for secondary D production. As reported in [11], the D meson production cross-sections in pp collisions at $\sqrt{s} = 7$ TeV are well described by predictions based on pQCD calculations as FONLL [8] and GM-VFNS [12]. To provide the reference cross-section at 2.76 TeV, needed to compute the $R_{\rm AA}$, the measurement at 7 TeV is scaled by the ratio of FONLL predictions for D meson production at $\sqrt{s} = 2.76$ and 7 TeV [13]. The uncertainty on the scaling decreases with p_t from 25% to 10%, as estimated by varying the parameters entering the FONLL calculations, namely the factorization and normalization scales and the charm quark mass. In March 2011 a sample of $\approx 6.5 \times 10^7$ events from pp collisions at $\sqrt{s} = 2.76$ TeV was collected. The D^0 and D^+ signals were measured in the $2 < p_t < 8$ GeV/c range. While the accumulated statistics did not allow for determining a pp reference over the whole momentum range, it served as an important cross check of the theoretical scaling procedure in the momentum range where the data sets overlap. Considering only the statistical errors, the ratio between the cross-section measured at 2.76 TeV and that obtained from the scaling of the measurement at 7 TeV is compatible with 1 within 1σ for the D^+ while, for the

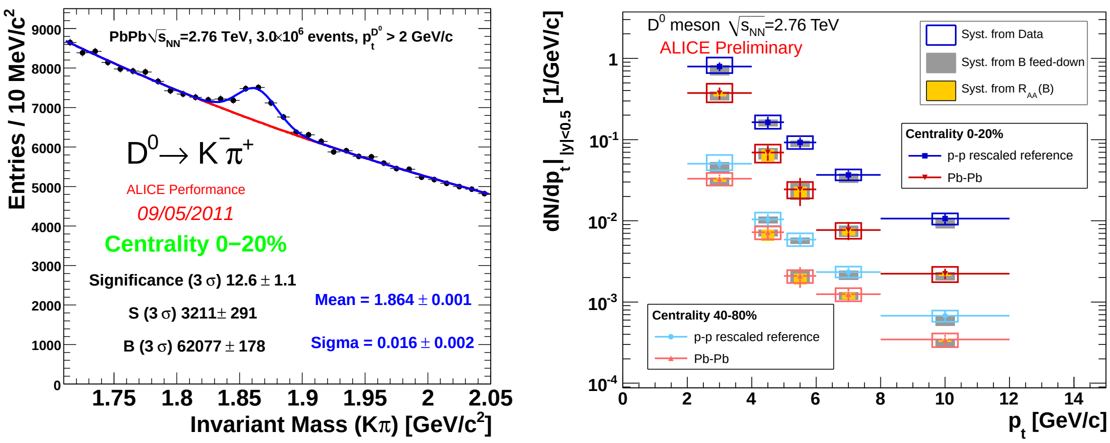

Figure 1. Left: invariant mass distributions of D^0 candidates for $p_\mathrm{t} > 2$ GeV/c obtained from the analysis of $\sim 3 \times 10^6$ central $(0-20\%)$ Pb–Pb events at $\sqrt{s_\mathrm{NN}} = 2.76$ TeV. The curves show the fit functions as described in the text. Right: D^0 spectra for central $(0-20\%)$ and peripheral $(40-80\%)$ Pb–Pb events at $\sqrt{s_\mathrm{NN}} = 2.76$ TeV compared to the reference spectra obtained by scaling the ALICE measurement in pp collisions at 7 TeV (see text).

D^0, within 1σ above 4 GeV/c and within 2σ for $2 < p_\mathrm{t} < 4$ GeV/c. A further 20% asymmetric contribution to the systematic error in the $2 < p_\mathrm{t} < 4$ GeV/c range has been added on the D^0 cross-section at 2.76 TeV used as the pp reference in the R_AA calculations. Figure 1 (right) shows the D^0 p_t spectra measured in central $(0-20\%)$ and peripheral $(40-80\%)$ Pb–Pb collisions, compared to their respective reference spectra.

3. D meson nuclear modification factors

The D meson production is suppressed by a factor 4-5 in central events for $p_\mathrm{t} \gtrsim 5$ GeV/c, as quantified by the nuclear modification factors shown in Fig. 2 (left). The D^0 and D^+ R_AA agree within errors. For the D^0, the statistical uncertainty is of the order of $20-25\%$, the estimated total systematic uncertainty, accounting for the uncertainties on the signal extraction procedure, on track reconstruction efficiency, on the MC corrections for reconstruction acceptance, cut and PID selection, and for possible differences in the D^0 and $\overline{\mathrm{D}^0}$ reconstruction varies from $^{+55\%}_{-26\%}$ for $2 < p_\mathrm{t} < 4$ GeV/c to $\pm 25\%$ for $8 < p_\mathrm{t} < 12$ GeV/c. The hypothesis on R^B_AA is varied in order to span the range $0.3 < R^\mathrm{D}_\mathrm{AA}/R^\mathrm{B}_\mathrm{AA} < 3$, with the $R^\mathrm{D}_\mathrm{AA}/R^\mathrm{B}_\mathrm{AA}$ calculated a posteriori. The range of R^D_AA values obtained in each p_t bin is considered as the systematic error due to the R^B_AA assumption. For the D^0, the maximum spread is of the order of 15% in the bin $2 < p_\mathrm{t} < 4$ GeV/c, 25% in the bin $4 < p_\mathrm{t} < 5$ GeV/c and 10% in the bin $8 < p_\mathrm{t} < 12$ GeV/c.

In central collisions, R_AA decreases with p_t from ~ 0.45 at low p_t to ≈ 0.2 at high p_t. The D meson R_AA is compatible within errors with the charged pion R_AA: the larger

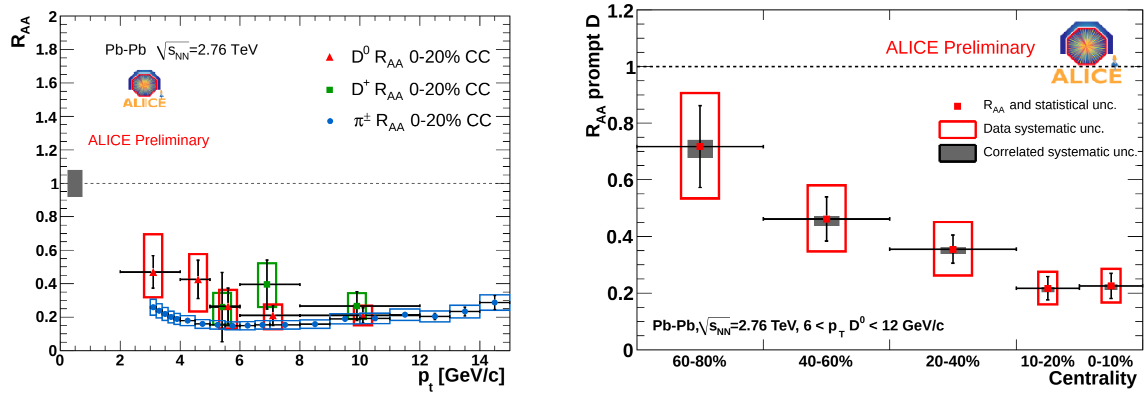

Figure 2. Left: D^0 and D^+ nuclear modification factor measured in central $(0-20\%)$ Pb–Pb collisions. The vertical lines represent the statistical errors. The filled grey box around $R_{AA} = 1$ represents the uncertainty on the normalization of the pp cross-section and on $\langle T_{AA} \rangle$. The empty boxes represent the total systematic uncertainties. The charged pions R_{AA} is shown for comparison. Right: D^0 nuclear modification factor as a function of centrality for $6 < p_t^{D^0} < 12$ GeV/c.

statistics expected from the higher luminosity Pb–Pb 2011 run and a reduction of the systematic errors should allow to conclude whether $R_{AA}^{D} > R_{AA}^{\pi^\pm}$ for $p_t \lesssim 5$ GeV/c and quantify the difference. The dependence on the centrality is shown in Fig. 2 (right) for $6 < p_t < 12$ GeV/c: R_{AA} decreases from ≈ 0.7 in peripheral $(60-80\%)$ to ~ 0.2 in central $(0-10\%)$ events. As verified by calculating the R_{AA} expected from pQCD calculation based on the MNR code [14] and nuclear PDF from EPS09 parametrization [15], nuclear shadowing yields a relatively small effect for $p_t \gtrsim 5$ GeV/c $(0.85 < R_{AA}^{D} < 1.08$ at $p_t = 5$ GeV/$c)$. Therefore, the observed suppression can be considered as an evidence of in-medium charm quark energy loss.

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