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Heavy-flavour production in small systems and evolution with multiplicity with ALICE

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Abstract.
In this report, highlights on the multiplicity-dependent measurements of heavy-flavour hadrons performed by the ALICE experiment, are presented. The heavy-flavour baryon-to-meson (Λ_c^+/D^0) and strange-to-non-strange D meson (D_s^+/D^0) ratios in different charged-particle multiplicity intervals are discussed. Recent measurements of heavy-flavour self-normalised yields as a function of the self-normalised charged-particle multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV are also reported. Measurement of jets containing heavy-flavour hadrons in pp and p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV and the recent measurements of azimuthal correlations of heavy-flavour hadron decay electrons and charged hadrons in pp collisions at $\sqrt{s}$ = 5.02 TeV are presented.

1 Introduction

Heavy quarks are produced through hard scattering processes of partons at the early stages of an ultra-relativistic heavy-ion collision. Hence, they act as sensitive probes for exploring the properties of the hot and dense deconfined matter formed in such collisions, known as the quark-gluon plasma (QGP) [1]. Heavy-flavour measurements in pp collisions are fundamental not only as reference measurements to investigate the properties of the QGP, since the latter is not expected to be formed in small systems, but are also important since they provide precise tests for the perturbative QCD calculations. The multiplicity dependent studies in pp and p–Pb collisions are important to further understand the particle production mechanisms in such systems, and can provide an insight into the the multiple-parton-interaction and colour reconnection phenomena in the hadronisation mechanisms of heavy-flavour particles.

In ALICE [2], the open heavy-flavour hadron production is studied through their different decay channels in a wide rapidity range. At mid rapidity, they are studied either through the reconstructed hadronic decays (e.g. $D^0 \rightarrow K^-\pi^+$, $D_s^+ \rightarrow K^-K^+\pi^+$, $D^+ \rightarrow K^-\pi^+\pi^+$, $D^* \rightarrow D^0\pi^+$, $\Lambda_c^+ \rightarrow pK^-\pi^+$, $\Lambda_c^+ \rightarrow pK_s^0$) or via the measurement of electrons from the semi-leptonic decays of heavy-flavour hadron (i.e. D, B $\rightarrow$ e + X) using the particle identification (PID) information from the Time Projection Chamber (TPC) and Time-Of-Flight (TOF) detectors. The Electromagnetic Calorimeter (EMCal) is employed along with the TPC for electron identification in the transverse momentum region $p_{\rm T} \gtrsim 4$ GeV/c. At forward rapidity, the open heavy-flavour hadron production is studied through the muons decayed from the heavy-flavour hadrons (i.e. D, B $\rightarrow \mu$ + X) using the Muon Spectrometer.

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2 Heavy-flavour production as a function of charged-particle multiplicity

Figure 1 shows the ratio of the yields of D_s^+ and Λ_c^+ with respect to the D^0 yield, on the left and right panels respectively, as a function of their transverse momentum (p_T) in different charged-particle multiplicity intervals in pp collisions at $\sqrt{s} = 13$ TeV. The D_s^+/D^0 ratio does

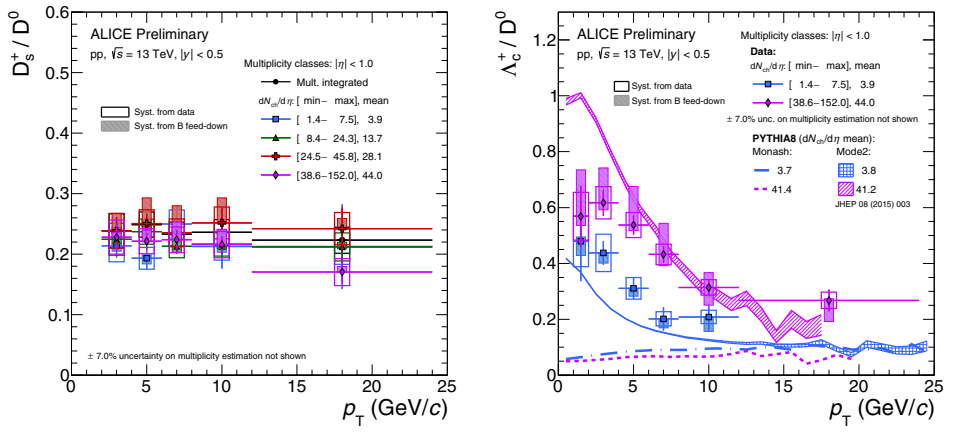

Figure 1. D_s^+/D^0 (left panel) and Λ_c^+/D^0 (right panel) ratio as a function of transverse momentum (p_T) in different charged-particle multiplicity intervals in pp collisions at $\sqrt{s} = 13$ TeV.

not show any dependence on charged-particle multiplicity within uncertainty and their abundance is compatible with the average of the p_T-integrated measurements performed in e^- e^+ collisions at LEP [3]. However, the Λ_c^+/D^0 ratio shows a significant increase from the lowest

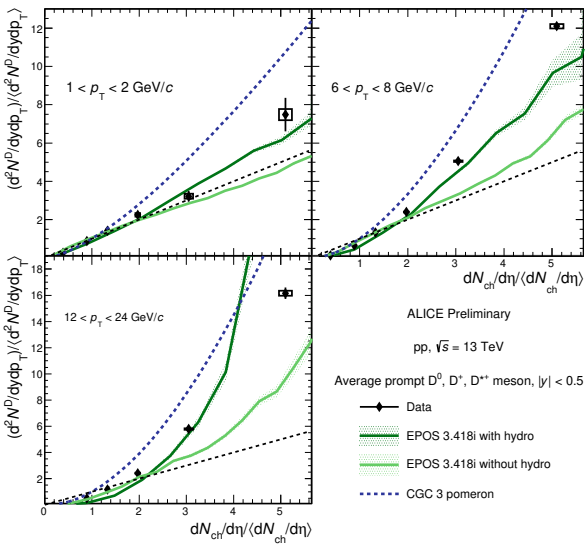

Figure 2. Self-normalised yield of D mesons as a function of the normalised charged-particle density in pp collisions at $\sqrt{s} = 13$ TeV, compared with predictions from EPOS3.418i (with and without hydrodynamics) and 3-Pomeron CGC models.

to the highest multiplicity indicating a modification of the hadronisation mechanisms from small to high multiplicity. The Λ_c^+/D^0 abundance is higher in the low-intermediate p_T region than the value measured in e^- e^+ collisions, indicating that the charm-quark fragmentation may not be universal. The Λ_c^+/D^0 measurement has also been compared with predictions from two different PYTHIA8 calculations. While predictions from default PYTHIA8 calculation (Monash tune) [4] largely underestimate the data, the predictions with colour reconnection mechanisms beyond the leading colour approximation (Mode2 tune) [5] describe the increasing trend of the baryon-over-meson ratio as a consequence of the new colour reconnection topologies included in the calculation.

Figure 2 shows the self-normalised yield of D mesons as a function of the normalised charged-particle density, in different p_T intervals, in pp collisions at $\sqrt{s}$ = 13 TeV. The term 'self-normalised' implies that the yield in multiplicity intervals are normalised by the average yield calculated in minimum-bias events. A faster than linear increasing trend of the self-normalised yield is observed in all p_T intervals, with higher p_T D mesons showing a steeper increase. The D meson self-normalised yields are compared with different theoretical predictions. The yields from the EPOS3.418i model [6] without hydrodynamical calculations and from the three-pomeron color-glass condensate (CGC) model [7] underestimate and overestimate the data respectively while the predictions from EPOS3.418i model with hydrodynamical calculations tend to describe the trend in data.

3 Heavy-flavour jets, correlations and flow

The study of jets containing heavy-flavour decay hadrons provides a direct access to the heavy-quark kinematics, and allows for studying possible modifications of its fragmentation in different multiplicity environments. Figure 3 shows the p_T-differential cross sections of

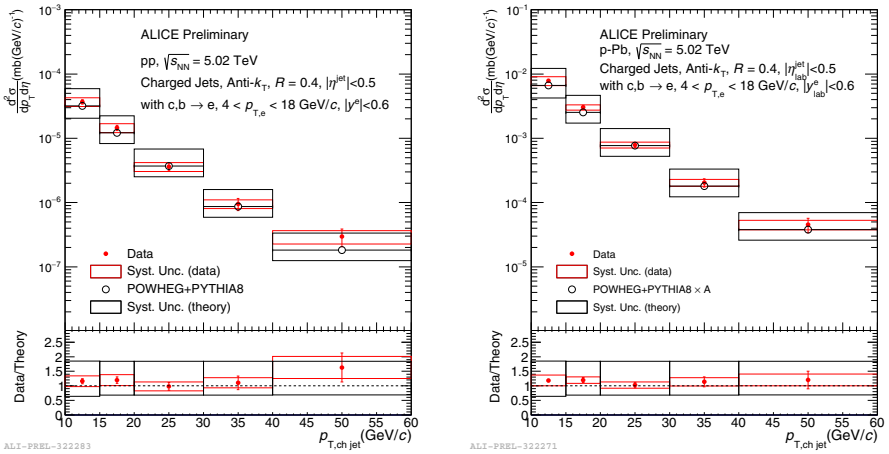

Figure 3. p_T-differential cross section of jets tagged with electrons from heavy-flavour hadron decay in pp (left panel) and p–Pb (right panel) collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.

jets tagged with electrons from heavy-flavour hadron decays in pp and p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV on the left and the right panels, respectively. The jets are identified by the presence of heavy-flavour decay electrons within 4 < $p_{T,e}$ < 18 GeV/c. The results have been compared with the next to leading order (NLO) perturbative QCD calculations using POWHEG + PYTHIA8 [4, 8] and are found to be in good agreement with NLO pQCD predictions.

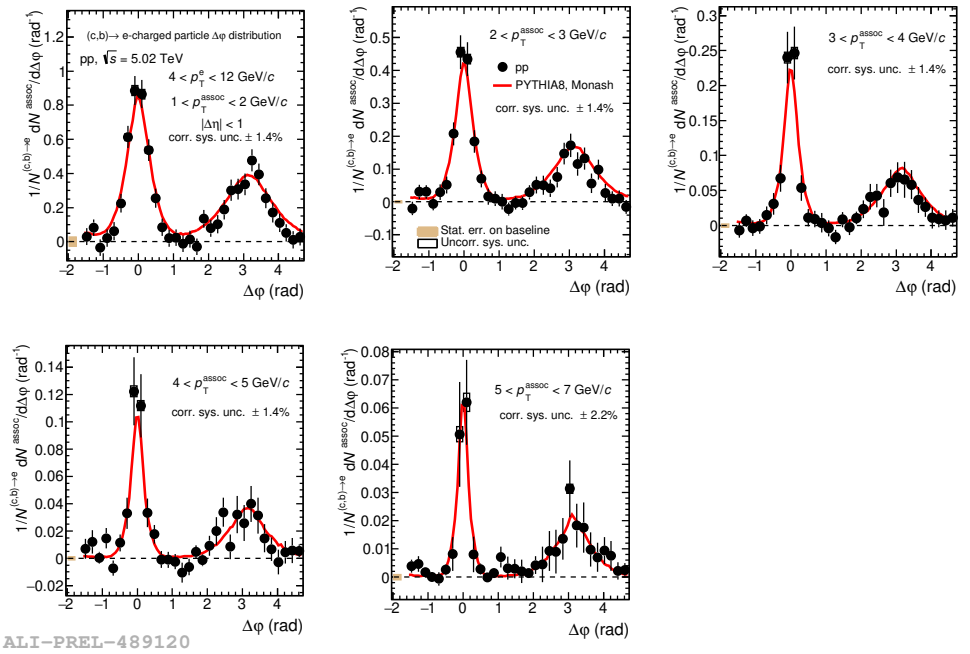

Figure 4. Azimuthal correlation between heavy-flavour hadron decay electrons and charged hadrons in pp collisions at $\sqrt{s} = 5.02$ TeV.

Figure 4 shows the azimuthal correlation between heavy-flavour hadron decay electrons and charged hadrons in pp collisions at $\sqrt{s} = 5.02$ TeV. Heavy-flavour hadron decay electrons within $4 < p_{\mathrm{T}} < 12$ GeV/c are chosen as trigger particles while charged hadrons in various intervals of p_{T} within 1 GeV/c and 7 GeV/c are chosen as associated particles as shown in the different panels of the figure. Predictions from PYTHIA8 (Monash tune) are consistent with the data. The near-side yield can be used to study modification of jet fragmentation while the away-side yield can provide information on the suppression and path length dependence of energy loss, and the correlation measurements in pp collisions will provide necessary reference for future heavy-ion measurements.

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