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Event-multiplicity and event-shape dependence of open heavy flavour production in pp collisions with ALICE at the LHC

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The excellent tracking and particle-identification capabilities of the ALICE detector allow us to fully reconstruct hadronic decays of open-charm hadrons at central rapidity and to study leptons from charm- and beauty-hadron decays at central and forward rapidities (y). In this contribution, we present the latest results on the production of D mesons reconstructed via hadronic decay channels ($|y| < 0.5$), open heavy flavour hadron decay electrons at mid-rapidity ($|y| < 0.8$), and open heavy flavour hadron decay muons at forward rapidity ($2.5 < y < 4$) in pp collisions at various collision energies. Precise measurements of the transverse momentum- and y-differential cross sections, which provide stringent constraints for pQCD calculations, are presented, along with comparison with model expectations. Also, the dependence of open heavy flavour production on the event-multiplicity is discussed. The dependence of the D^0 production on the event multiplicity and spherocity in pp collisions at $\sqrt{s}$ = 7 TeV is also reported.

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1. Introduction

Heavy-quarks are sensitive probes for investigating the properties of the hot and dense medium formed in heavy-ion collisions. Their investigation in proton-proton (pp) collisions at the LHC, besides furnishing the necessary baseline for measurements in nucleus–nucleus collisions, provides precise tests for perturbative QCD (pQCD) calculations based on the factorisation approach down to very low Bjorken-x values. The analysis of heavy flavour production as a function of the multiplicity of charged particles produced in the collision and of event-shape variables, like spherocity, which classify events according to their topology, can give insight into multiple-parton-interaction phenomena. These studies provide a handle to understand the interplay of hard and soft processes and to search possible connections between small and extended interacting systems.

2. Open heavy flavours with the ALICE detector

Open heavy flavours are studied in ALICE [1] in different rapidity (y) ranges either through reconstructed hadronic decays, as in the case of D mesons and charmed-baryons, or via the measurement of leptons from semi-leptonic heavy flavour hadron decays (i.e. $\mathrm{D,B} \rightarrow \mathrm{e}/\mu + \mathrm{X}$). The reconstructed D mesons from hadronic decay channels ($|y| <0.5$) and electrons from open heavy flavour hadron decays ($|y| <0.8$) are studied at mid-rapidity using particle identification (PID) information from the Time Projection Chamber (TPC) and Time-Of-Flight (TOF) detectors. The ElectroMagnetic Calorimeter (EMCal) is used in addition to the TPC for electron identification for transverse momentum (p_{T}) larger than 4 GeV/c. Muons from semi-leptonic decay channels are selected using the Muon Spectrometer in the forward pseudorapidity range ($-4.0 < \eta < -2.5$). The number of tracklets obtained from the Silicon Pixel Detector (SPD) within $|\eta| < 1$ is used for the multiplicity measurement.

3. D meson production cross section

The non-strange D meson (D^{*+}, D^0, D^+) cross sections at different collision energies are shown in Fig. 1. The data are compared with the pQCD calculations obtained from the Fixed Order plus

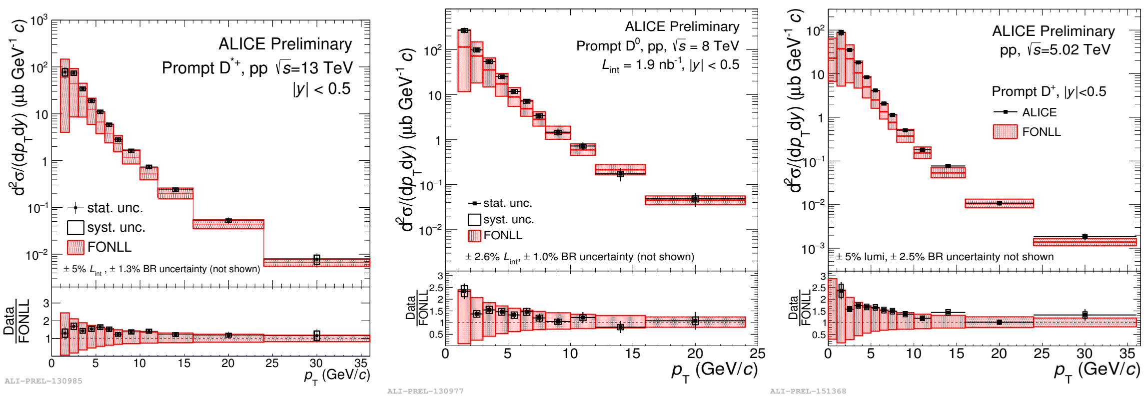

Figure 1: D meson cross section at different collision energies.

Next-to-Leading Logarithms approach (FONLL) [2, 3]. The D meson cross section is described well by the FONLL calculation over a wide p_{T} range and the central values of the prediction lie below the data for all the considered D meson species and collision energies. Figure 2 shows the ratios of the p_{T}-differential cross sections of D^0, D^{*+}, D^+, D_s^+ mesons at $\sqrt{s}$ = 5.02 TeV and $\sqrt{s}$ = 7 TeV. No significant p_{T} dependence is observed within the experimental uncertainties suggesting a small difference between the fragmentation functions of the different species. The energy dependence of D meson cross section is shown in Fig. 3. The top panel shows the D^+ cross section ratio at $\sqrt{s}$ = 13 TeV and $\sqrt{s}$ = 5 TeV and the bottom panel shows the D^0 cross section ratio at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 5 TeV. The results are compared with the FONLL calculations, which

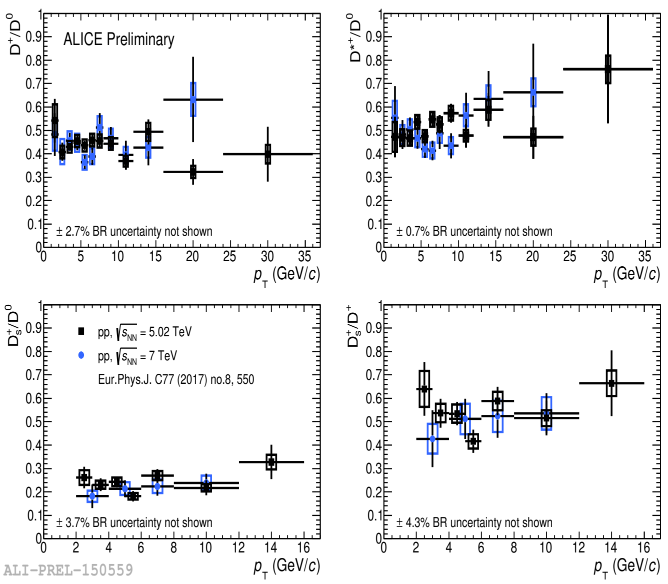

Figure 2: Ratios of the cross sections of D^0, D^{*+}, D^+, D_s^+ mesons at $\sqrt{s}$ = 5.02 TeV and $\sqrt{s}$ = 7 TeV.

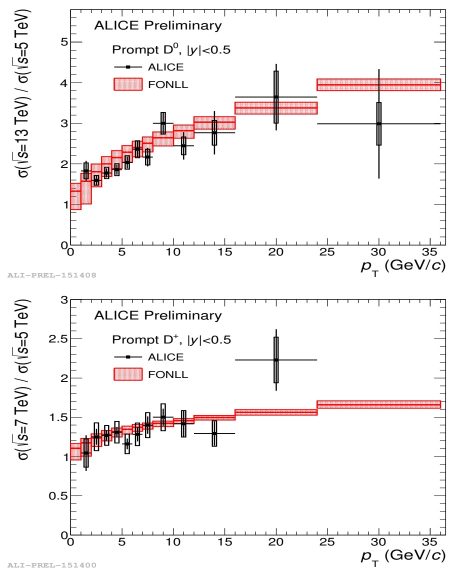

Figure 3: Ratio of D^0 meson cross sections at $\sqrt{s}$ = 13 TeV and $\sqrt{s}$ = 5 TeV (top panel) and $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 5 TeV (bottom panel).

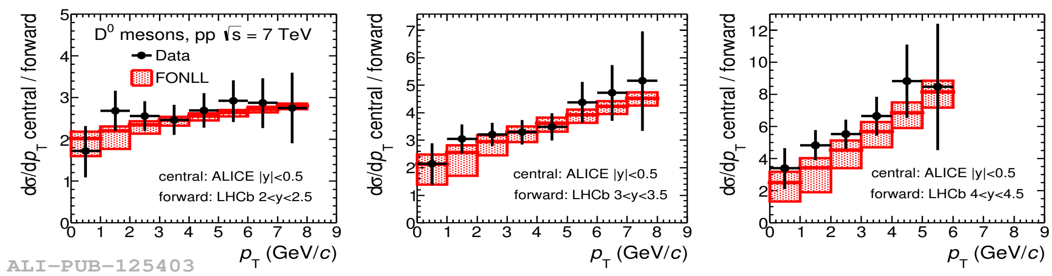

Figure 4: D^0 meson central-to-forward ratios at $\sqrt{s}$ = 7 TeV are shown as a function of p_{T} for $|y| < 0.5$ at mid rapidity and three different y intervals at forward rapidity: $2 < y < 2.5$, $3 < y < 3.5$, $4 < y < 4.5$.

serves as an additional test for pQCD calculations. The FONLL prediction describes consistently the slightly increasing trend of the data as a function of p_{T}. The data at different energies in mid-rapidity and forward-rapidity regions are useful to set constraints on the gluon PDF [4]. Figure 4 shows the D^0 meson central-to-forward ratios at $\sqrt{s}$ = 7 TeV by using ALICE data [5] at mid-rapidity ($|y| < 0.5$) and LHCb data [6] in three different y intervals at forward rapidity ($2 < y < 2.5$, $3 < y < 3.5$, $4 < y < 4.5$).

4. heavy flavour semi-leptonic decays

The p_{T}-differential cross sections of the muons and electrons from decays of open heavy flavour hadrons (c,b $\rightarrow \mu$/e) at $\sqrt{s}$ = 5.02 TeV are shown in the left and right panel of Fig. 5 respectively, along with the comparison with the pQCD FONLL calculation. The data lie on the upper edge of the theoretical (FONLL) uncertainty band for both electrons and muons. The c $\rightarrow \mu$ and b $\rightarrow \mu$ cross sections from FONLL predictions are also shown separately (left panel) which give an insight about the relative abundance of beauty and charm quarks from the muon cross section i.e., at low p_{T} charm decay is dominant while the beauty is the main component for $p_{\mathrm{T}} \gtrsim 5$ GeV/c. Figure 6

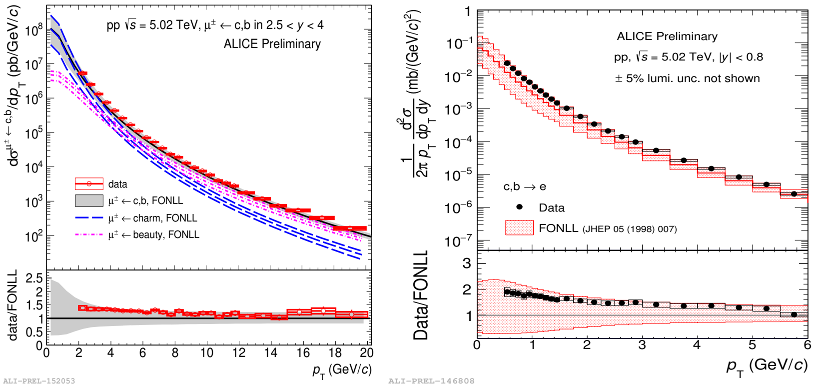

Figure 5: p_{T}-differential cross sections of the open heavy flavour hadron decay muons (left panel) and open heavy flavour hadron decay electrons (right panel) at $\sqrt{s}$ = 5.02 TeV.

shows the multiplicity dependent self-normalised yields for c,b $\rightarrow \mu$ at $\sqrt{s}$ = 8 TeV (left panel) and c,b $\rightarrow$ e at $\sqrt{s}$ = 13 TeV (right panel), which follow a faster than linearly increasing trend. Higher p_{T} ranges show a tendency for steeper increase. A difference in the trend of the self-normalised

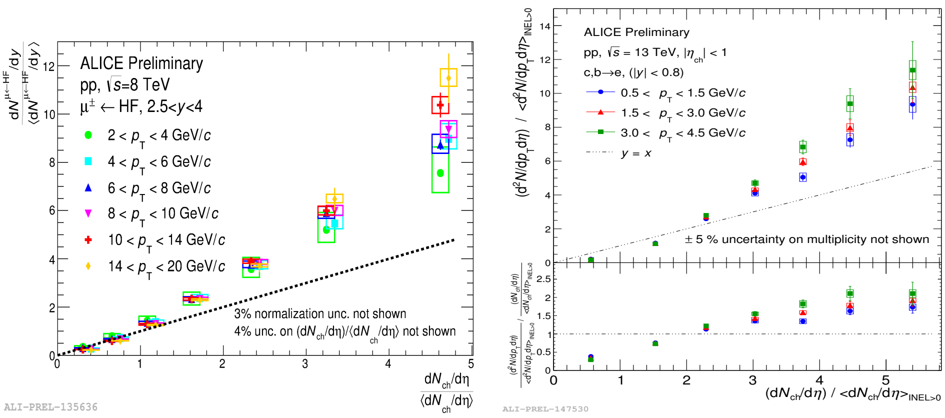

Figure 6: Multiplicity dependent self-normalised yields of open heavy flavour hadron decay muons at $\sqrt{s}$ = 8 TeV (left panel) and electrons at $\sqrt{s}$ = 13 TeV (right panel).

yields at mid rapidity (c,b $\rightarrow$ e, $|y|$ <0.8 and D mesons, $|y|$ <0.5) and at forward rapidity (c,b $\rightarrow \mu$, 2.5< y <4) is observed as shown in Fig. 7. This difference may possibly arise from autocorrelation effects and jet bias, due to the overlap in the rapidity regions of the multiplicity estimator (number of tracklets from the SPD within pseudorapidity range $|\eta| < 1$) and heavy flavour yield (c,b $\rightarrow$ e, D mesons at mid rapidity), which is absent for the c,b $\rightarrow \mu$ case.

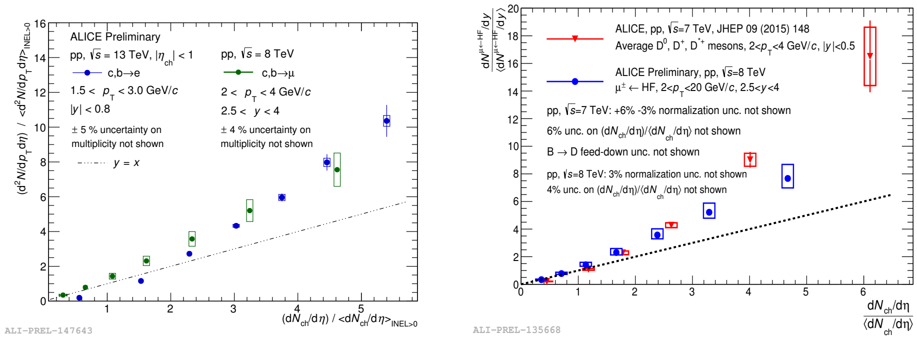

Figure 7: Comparison of self-normalised yield at mid rapidity ($|y|$ <0.8 for c,b $\rightarrow$ e (left panel), $|y|$ <0.5 for D mesons (right panel)) and at forward rapidity (c,b $\rightarrow \mu$ in 2.5< y <4).

5. D^0 meson production vs. spherocity

The value of spherocity (S_0) runs from 0 to 1, as the distribution of particles deviates from the jetty-like (hard events) to an isotropic structure (soft events). The D^0 meson relative yield production as a function of spherocity is shown in Fig. 8. The left panel shows the D^0 meson relative yield at low multiplicity ($20 < N^{\mathrm{SPD}}_{\mathrm{tracklets}} < 30$) and the right panel at higher multiplicity ($30 < N^{\mathrm{SPD}}_{\mathrm{tracklets}} < 81$). A higher rate of high-p_{T} D mesons is seen in low-spherocity events, as expected from the jet contribution to the event spherocity. A similar rate of low p_{T} D mesons is observed at different spherocity. The trend of D^0 production remains the same for two different multiplicity regions. The data trend is reproduced by PYTHIA8 [7] in both multiplicity intervals.

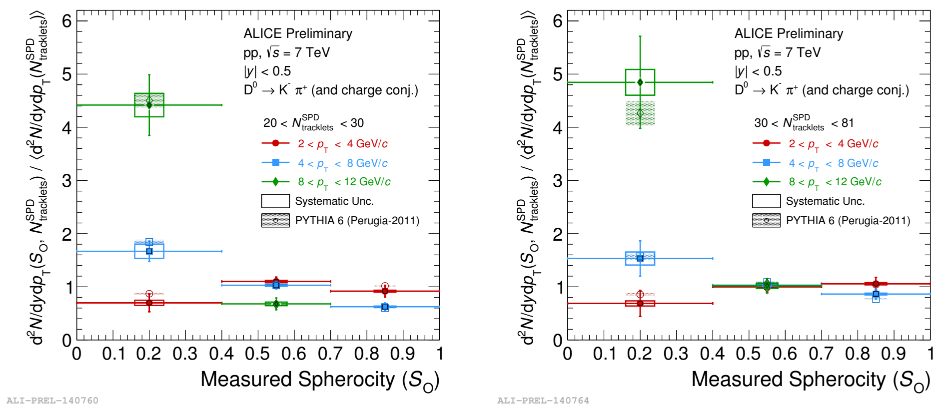

Figure 8: D^0 meson relative yield production as a function of spherocity at $\sqrt{s}$ = 7 TeV. Left panel: Low multiplicity range ($20 < N^{\mathrm{SPD}}_{\mathrm{tracklets}} < 30$); Right panel: High multiplicity range ($30 < N^{\mathrm{SPD}}_{\mathrm{tracklets}} < 81$).

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