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Heavy-flavor measurements in proton-proton collisions with ALICE at the LHC

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The study of heavy-flavor production in proton-proton collisions is of particular interest for quantum chromodynamics (QCD), as charm and beauty quarks possess large masses and are thus mainly created in hard partonic scattering processes. Cross sections obtained from measurements of charm and beauty hadrons allow to constrain theories and to provide important parameters for model calculations. The ALICE experiment recently provided measurements in a higher, so far unexplored energy region, which allows for the first tests of predictions of p_{T}-differential cross sections from pQCD in this new energy domain.

In the ALICE detector system, heavy-flavor hadron production is measured through the reconstruction of hadronic decays of D mesons at mid-rapidity and via semileptonic decay channels of charm and beauty hadrons at forward and mid-rapidity. We report on the analysis performed in pp collisions at center of mass energies of 2.76 and 7 TeV at the LHC which allowed us to measure the p_{T}-differential cross section of D mesons and leptons from decays of heavy-flavor hadrons. Furthermore, the D-meson yield at mid-rapidity was also studied as a function of the multiplicity of charged particles produced in the collision. We discuss recent results from these analyses.

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1. Introduction

The Large Hadron Collider (LHC) opens a completely new window in terms of energy to test predictions of perturbative Quantum ChromoDynamics (pQCD) calculations and models. Heavy flavor is one particular probe one can look at. The heavy quarks charm and beauty are, due to their large mass ($m_c \sim 1.5$ GeV$/c^2$, $m_b \sim 5$ GeV$/c^2$), nicely separated from the light-flavor sector. As a consequence, heavy quarks are predominantly produced in hard partonic scattering processes with short formation time. The high momentum transfer q^2 allows perturbative calculations. The measurement of heavy-flavor production at the LHC is of particular interest because of a large production cross sections. The energy of $\sqrt{s}$ = 7 TeV provides with 3.5 x $\sqrt{s_{Tevatron}}$ a significantly higher energy domain for pQCD tests.

This paper introduces first the heavy-flavor measurements with the ALICE detector. Results for D mesons and leptons from heavy-flavor hadrons are presented in the following sections.

1.1 Heavy-Flavor measurements with the ALICE detector

ALICE [1] is primarily targeted towards heavy-ion collisions. Its capabilities to measure charged particles down to low p_T makes it also suitable for heavy-flavor measurements in proton-proton collisions. The decay of heavy-flavor hadron ground states via weak interaction results in a decay length for D mesons of $c\tau$ 100-300 μm, and for B mesons of $c\tau \sim 500$ μm. The separation from the vertex by a few hundred μm is exploited to detect particles originating from heavy-flavor decays. Several detectors are involved in the analysis. The Inner Tracking System (ITS) provides vertexing and tracking together with the Time Projection Chamber (TPC). The analysis uses furthermore the capabilities of particle identification (PID) of the TPC and further detectors, namely Time-of-flight (TOF) detector, Transition Radiation Detector (TRD), and electromagnetic calorimeter (EMCAL). In the forward rapidity region, muon tracks are reconstructed in the muon spectrometer (MUON).

Hadronic decays of D mesons are detected with the central barrel detectors in the rapidity range $|\eta| < 0.8$ for $p_T > 1$ GeV$/c$. Semileptonic decays are detected in the central and forward rapidity region:

$$\text{b/c} \rightarrow \text{e} + \text{X} : |\eta| < 0.8,\ p_T > 0.5\ \text{GeV}/c$$

$$\text{b/c} \rightarrow \mu + \text{X} : -4 < \eta < -2.5,\ p_T > 2\ \text{GeV}/c$$

2. D meson cross sections

A topological reconstruction of secondary vertices with significant separation from the primary vertex was used to reconstruct D mesons. The analysis includes the production of D^0, D^+, D^{*+}, and D_s^+ via the decay channels $D^0 \rightarrow K^-\pi^+$, $D^+ \rightarrow K^-\pi^+\pi^+$, $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$, and $D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+$. The candidate pairs and triplets have been treated in an invariant mass analysis, where particle identification in the TPC and TOF detectors provided additional background rejection in the low-momentum region. The yield is extracted from a fit to the invariant mass distribution where the background fit function is determined from the sidebands.

Figure 1 shows the p_T-differential cross sections for prompt D mesons at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 2.76 TeV. The analysis was carried out in discrete bins in p_T between 1 GeV$/c$ and an upper limit depending on the available statistics for different analyses: 16 GeV$/c$ for D^0at $\sqrt{s}$ = 7 TeV (9 bins), 24 GeV$/c$ for $D^+$and D^{*+}at $\sqrt{s}$ = 7 TeV (10 bins), and 12 GeV$/c$ for mesons at $\sqrt{s}$ = 2.76 TeV. The contribution from beauty feed down was estimated based on FONLL [4] pQCD calculations and subtracted. The production of the charm-strange meson D_s^+ has been studied at $\sqrt{s} = 7$ TeV as shown in Figure 2 [7].

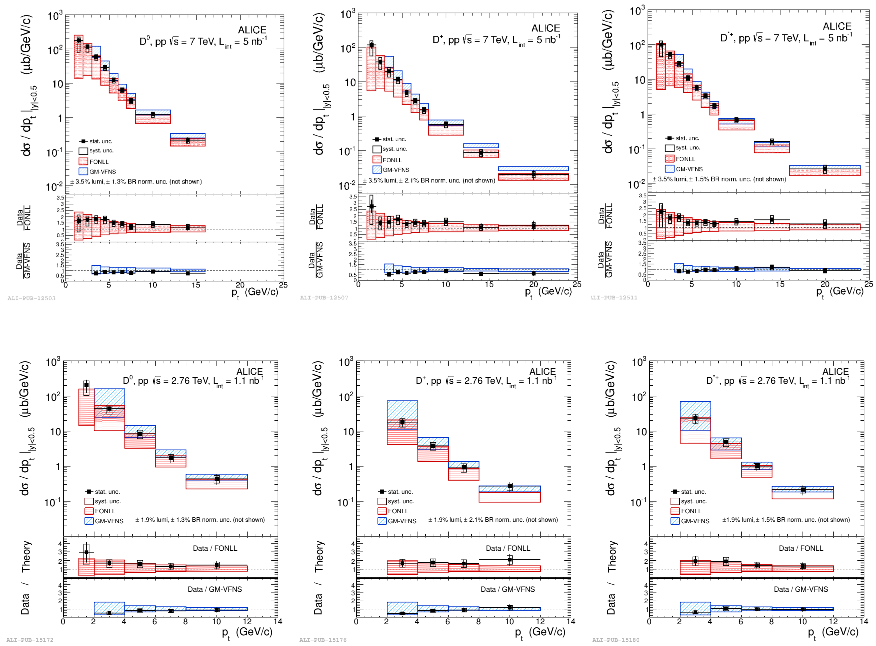

Figure 1: Prompt D meson production cross sections in pp collisions at $\sqrt{s} = 7$ TeV [3] (upper row) and $\sqrt{s} = 2.76$ TeV [2] (lower row).

The results have been compared to several pQCD calculations, Fixed-Order-Next-to-Leading-Log (FONLL) [4], General-Mass Variable-Flavor-Number Scheme (GM-VFNS) [5], and k_t factorization approach [6]. Data are well described by pQCD calculations within uncertainties.

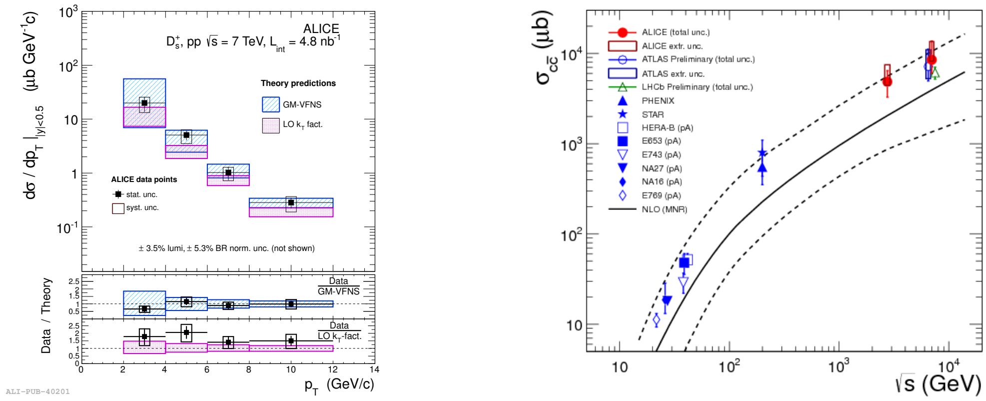

Figure 2: Left: p_T-differential inclusive cross section for prompt D_s^+ meson production at $\sqrt{s} = 7$ TeV [7], Right: Total charm production cross section as a function of $\sqrt{s}$ [2]. NLO MNR calculation (uncertainties) are represented by solid (dashed) lines [8].

The presented analyses allow to calculate the total charm production cross section at two energies in pp collisions at the LHC. Figure 2 compiles cross sections measured with different experiments as a function of $\sqrt{s}$. In case of proton-nucleus (pA) or deuteron-nucleus (dA) collisions, measured cross sections were scaled down by the number of binary nucleon-nucleon collisions (Glauber model calculation). Comparison to an early NLO calculation [8] shows agreement with data within the uncertainties of the calculation. The data fall in the upper part of the theoretical uncertainty band at all energies.

In Figure 3 the results for production ratios of different types of D mesons are shown. Model calculations show good agreement with data. We observe a suppression of charm-strange mesons in the fragmentation of the charm quark. This suppression looks similar at different energies and in other systems. We also note a good agreement between ALICE and LHCb results.

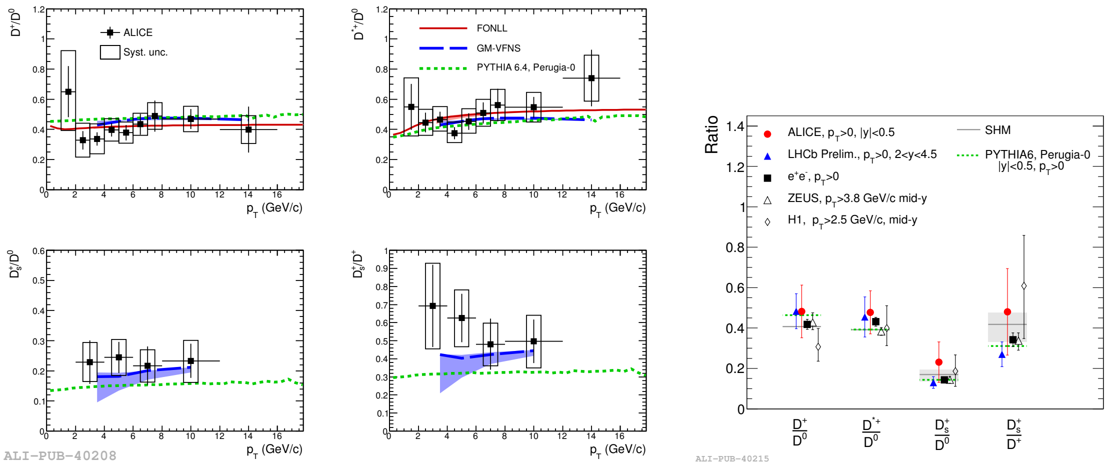

Figure 3: Ratios of D meson yields. Left, middle: ratios of cross sections as a function of p_T, Right: ratios of p_T-integrated cross section compared to results from other experiments [7].

In order to investigate the role of multi-parton interactions on a hard scale, D-meson production has been studied as a function of the multiplicity of charged particles produced in pp collisions at $\sqrt{s}$ = 7 TeV. Preliminary results are shown in Figure 4. We observe an increase of the yield with charged-particle multiplicity and good consistency between the measurements of D^0, D^+, and D^{*+}. There is no evident p_T dependence within uncertainties.

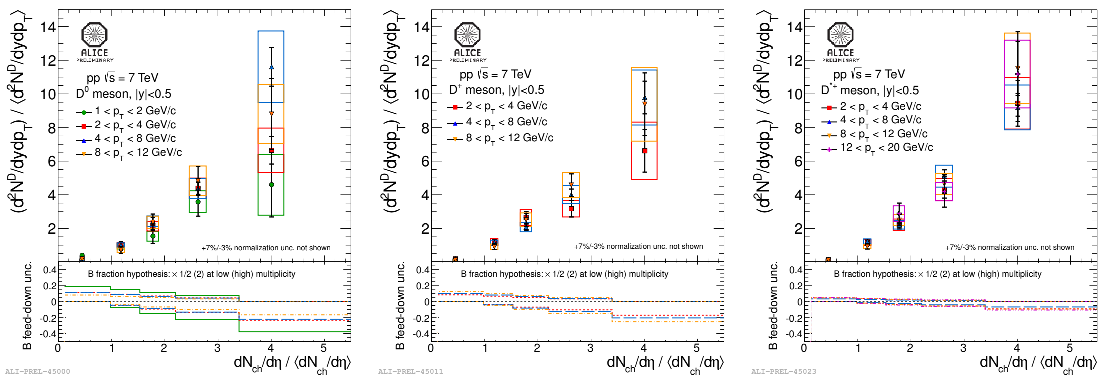

Figure 4: D-meson production as a function of charged-particle multiplicity in pp collisions at $\sqrt{s}$ = 7 TeV.

3. Semileptonic decay channels

The measurement of the production cross section of electrons originating from the decay of heavy-flavor hadrons is based on the measurement of inclusive electrons and the subtraction of a cocktail of the known background sources calculated from the measured π^0 spectrum and m_T scaling. Details of the analysis can be found in [9, 11].

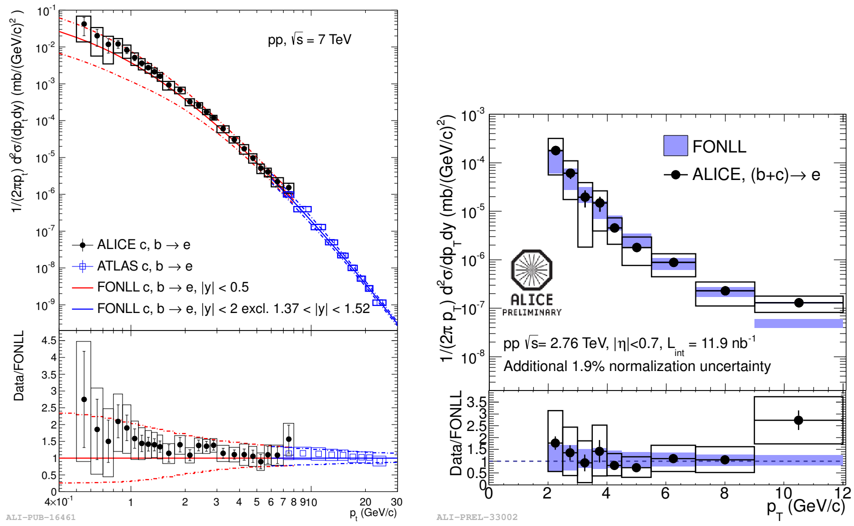

Figure 5: Left: Invariant differential production cross sections of electrons from heavy-flavor decays measured by ALICE and ATLAS [10] in pp collisions at $\sqrt{s} = 7$ TeV [9]. Right: production cross section at $\sqrt{s} = 2.76$ TeV.

Results at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 2.76 TeV are shown in Figure 5. Data at both energies are well described by FONLL calculations within theoretical uncertainties. Results at $\sqrt{s} = 7$ TeV are complementary to ATLAS results at high p_{T}.

Production of beauty at mid-rapidity has been studied by using the large displacement of B-decay electrons and setting an appropriate cut on impact parameter [11]. Contributions of beauty and charm decays to the total differential cross section is shown in Figure 6. In the left panel of Figure 6, the p_{T}-differential production cross section of electrons from beauty-hadron decays is shown and compared to that of electrons from D hadron decays and FONLL predictions. In the right panel of Figure 6, the cross section obtained with the impact parameter selection is compared to a preliminary result based on displaced secondary vertices. Both are described well by FONLL pQCD predictions down to low p_{T}. Preliminary results of a complementary method based on electron-hadron azimuthal correlations is presented in Figure 7.

ALICE has access to the forward rapidity region through the MUON spectrometer. Heavy-flavor production has been measured through the semi-muonic decay channel in the rapidity range $2.5 < y < 4$ for $p_{\mathrm{T}} > 2$ GeV$/c$. The identification of muons from charm and beauty decays is based on the p_{T} distribution of reconstructed muon tracks. The p_{T} shape of different sources of background are estimated using a MC simulation normalized to data at low p_{T}. The results of p_{T}- and y-differential cross sections are shown in Figure 8.

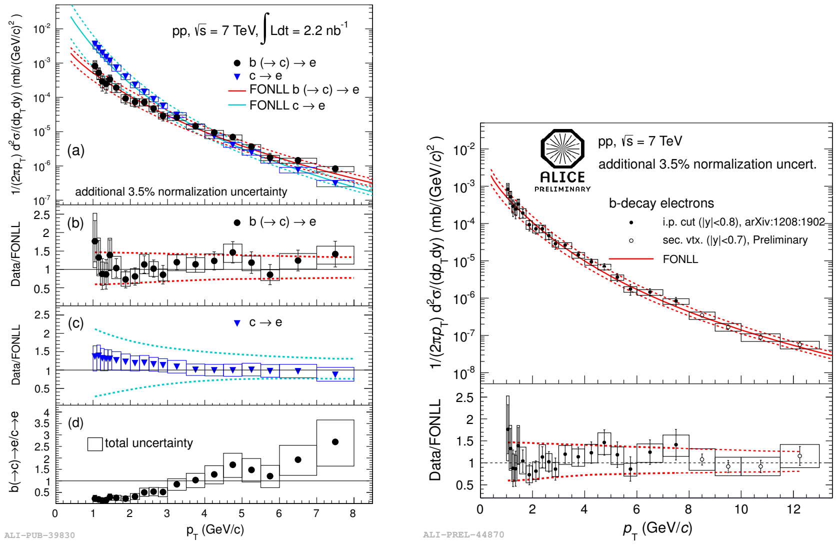

Figure 6: p_{T}-differential production cross section of electrons from beauty-hadron decays at mid-rapidity in pp collisions at $\sqrt{s} = 7$ TeV [11].

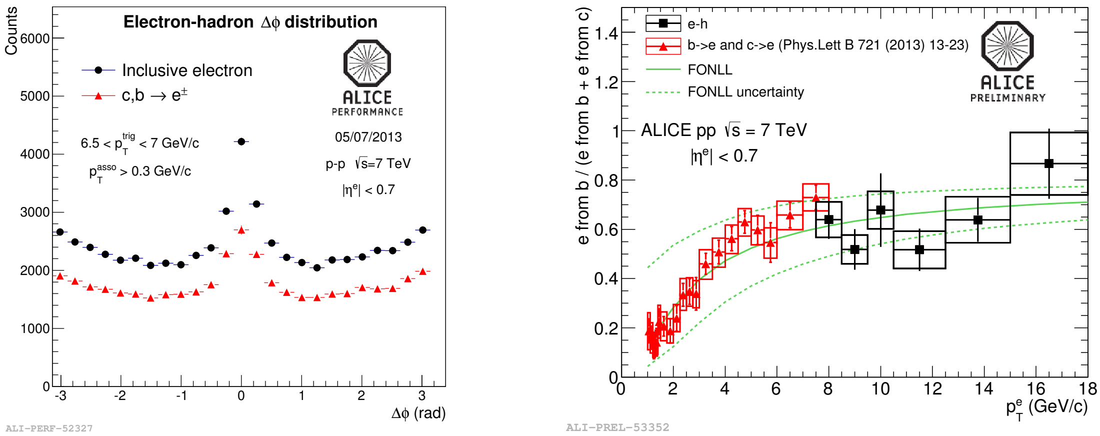

Figure 7: Left: Comparison of inclusive and heavy-flavor electron-hadron azimuthal angular correlations in pp collisions at $\sqrt{s} = 7$ TeV. Right: Relative beauty contribution to the heavy-flavor electron yield using the impact-parameter method ($p_{\mathrm{T_e}}$<8 GeV/c) and the e-h correlation method ($p_{\mathrm{T_e}}$>7.5 GeV/c).

p_{T}- and y-differential cross sections are in good agreement with FONLL pQCD calculations within experimental and theoretical uncertainties. Data are close to the upper limit of the model calculations. Similar observations have been made in pp collisions at $\sqrt{s} = 2.76$ TeV [13].

4. Conclusions

With ALICE, the production cross section of charmed mesons and leptons from heavy-flavor decays at mid and forward rapidity has been measured in proton-proton collisions at $\sqrt{s} = 2.76$ TeV

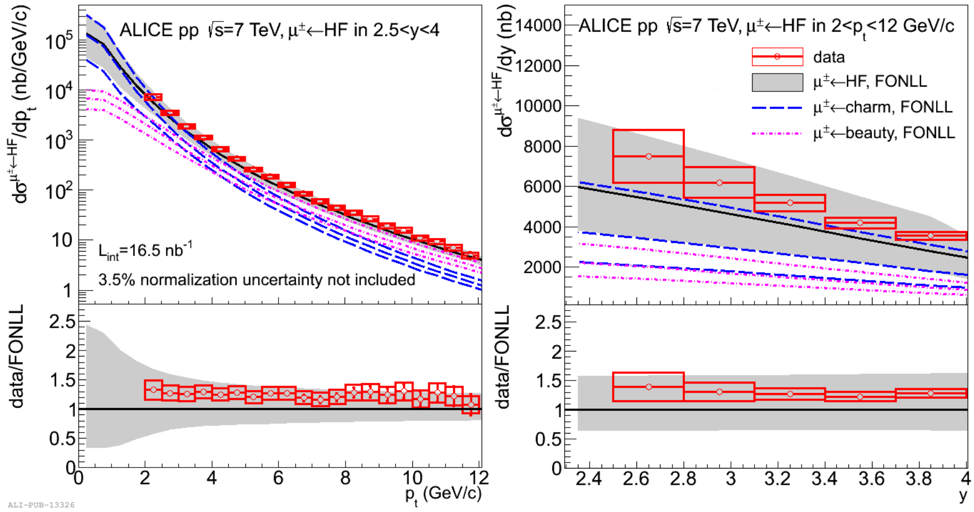

Figure 8: Production cross section of muons from heavy-flavor decays at forward rapidity at $\sqrt{s}$ = 7 TeV. Left: p_{T}-differential production cross section Right: y-differential production cross section in the range $2 < p_{\mathrm{T}} < 12$ GeV/c [12].

and $\sqrt{s}$ = 7 TeV. D meson p_{T}-differential cross sections are measured down to 1 GeV/c. Ratios of the cross sections of D^0, D^+, $\mathrm{D}^{*+}$and D_s^+ agree with results obtained at different energies and in different collision systems. The measured differential and total cross sections are reproduced by pQCD calculations within experimental and theoretical uncertainties. An increasing D-meson yield with charged particle multiplicity is observed and could be due to multipartonic interaction at hard momentum scales. ALICE complements other LHC experiments accessing the low p_{T} region both for charm and beauty.

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