Heavy Flavour Physics with the ALICE detector at the CERN-LHC

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Abstract. Heavy quarks have been proposed as powerful probes to study hot quark matter produced in high-energy heavy-ion collisions. The measurement of the charm and beauty production cross sections in pp collisions provides a reference for the studies in heavy ion collisions. Moreover, the pp measurements at LHC will allow to test the perturbative QCD calculations in a totally new energy domain. In this contribution we present the first results from the analysis of charm and beauty production in pp collisions at $\sqrt{s} = 7$ TeV with the ALICE experiment, using the hadronic D meson and semi-leptonic D and B meson decays. In this talk I will present the first cross section measurement of muons from heavy flavour decays at forward rapidity and the heavy flavour electron spectra at central rapidity. We report on the first D meson cross section at central rapidity and the $J/\psi$ production cross section at central and forward rapidity.

1. Introduction
The main goal of the ALICE [1, 2] experiment is to study the strongly interacting matter in the conditions of high density and temperature. In such conditions lattice QCD calculations predict quark de-confinement and the formation of the so called Quark-Gluon Plasma (QGP) [3]. Heavy flavour hadrons are excellent probes for the investigation of the QGP. Open charm and beauty hadrons are expected to be sensitive to the energy density through the in-medium energy loss of the heavy quarks. Quarkonium states are sensitive to the initial temperature of the system via their dissociation due to color screening. A detailed discussion on physics motivation for heavy flavour measurements in Pb-Pb collisions can be found in Refs. [1, 2]. In this paper we discuss the preliminary ALICE results on heavy flavour production in pp collisions at $\sqrt{s} = 7$ TeV. The proton-proton results provide the baseline for the study of medium-induced effects in nucleus-nucleus collisions. Moreover they offer the possibility to test pQCD in the new energy domain of the Large Hadron Collider. Perturbative QCD predictions extracted using FONLL [4] (Fixed-Order-plus-Next-to-Leading-Log) describe well the beauty production cross section measured in pp collisions at $\sqrt{s} = 1.96$ TeV by CDF at the Tevatron [5]. Additionally, the CMS experiment found that at the LHC energy scale ($\sqrt{s} = 7$ TeV) the beauty production is well described by the theory [6]. In the case of charm, FONLL prediction agrees with data within errors. Nevertheless, the data points are systematically on the upper edge of the theory error band suggesting that charm production could be underestimated in the calculation as also seen at RHIC energies ($\sqrt{s} = 0.2$ TeV) [7, 8]. Concerning the quarkonium production, several models have attempted to
describe the hadroproduction of quarkonium states at Tevatron energies but failed to reproduce simultaneously the production cross section, transverse momentum distribution and polarization.

2. The ALICE detector and running conditions

The ALICE apparatus [1] has excellent capabilities for heavy-flavour measurements, for both open heavy-flavoured hadrons and quarkonia. It is composed of a central barrel and a forward muon arm. The central barrel covers the pseudo-rapidity region $-0.9 < \eta < 0.9$ and is equipped with tracking detectors and particle identification systems embedded in a magnetic field $B=0.5$ T along the $z$-axis. The Inner Tracking System (ITS) is the innermost central barrel detector and it is composed of six cylindrical layers of silicon detectors. The two layers closest to the beam pipe, positioned at radii of $\sim 4$ and $7$ cm, are equipped with pixel detectors. The two intermediate layers, at radii $\sim 15$ and $24$ cm, are made of drift detectors. The two outermost layers, at radii $\sim 39$ and $44$ cm, use strip detectors. Using ITS the track impact parameter (i.e. the distance of the closest approach of the track to the primary vertex) can be measured with a resolution better than $70 \mu$m for $p_T \simeq 1$ GeV/c, thus providing the capability to detect the secondary vertices originating from heavy-flavour decays ($ct \sim 100-300 \mu$m for D mesons). As standalone tracker the ITS allows to track particles down to $p_T \sim 70$ MeV/c. The Inner Tracking System is surrounded by the main ALICE tracking detector, a 510 cm long cylindrical Time Projection Chamber (TPC). It provides track reconstruction with up to 160 three-dimensional space-points as well as particle identification via specific energy deposit $dE/dx$. The TPC hadron identification capability is complemented by the Time-Of-Flight detector (TOF) and the Transition Radiation Detector (TRD). All mentioned detectors have full azimuthal coverage. The TRD is surrounded by a large acceptance (110 degrees azimuthal and $-0.7 < |\eta| < 0.7$) electromagnetic calorimeter (EMCal) providing an efficient and fast trigger for electron measurements.

The ALICE muon spectrometer is located at large rapidity $-4 < \eta < -2.5$. It is made of five tracking stations with two planes of multi-wire proportional chambers each, having a spatial resolution of about $100 \mu$m. The muon spectrometer is completed by a dipole magnet with an integral field of $3$ Tm and two trigger stations of resistive plate chambers placed behind an iron-wall muon filter with a thickness of about 7 interaction lengths. The system is completed by a frontal absorber of composite material. The spectrometer can detect quarkonia down to $p_T = 0$. The results presented in this paper are based on the 2010 minimum bias (MB) data sample [9]. It is defined as the logical “OR” of at least one of the pixel tracker layers and two rings of forward scintillator detectors $(V0A$ and $V0C$, placed asymmetrically with respect to the interaction point) is required. At least one charged particle over eight rapidity units is requested and all the ALICE detector is read out. This trigger configuration is sensitive to about 87% of the pp inelastic cross section. A muon trigger was also used during the 2010 data taking. In addition to the MB conditions, it requires at least one trigger signal ($p_T > 0.5$ GeV/c).

3. Electrons from heavy flavours decays

The semi-leptonic decay of D and B mesons, with a branching ratio of $\sim 10 \%$, gives access to the investigation of open charm and beauty production. The identification of the electrons is assured by the excellent particle identification of the ALICE central barrel detectors, namely TPC, TOF, TRD and EMCal. The results presented in this paper are obtained using TPC and TOF as PID detectors. The TRD and EMCal will allow us to extend the $p_T$ reach.

The extraction of the production cross section of the heavy flavour decay electrons can be performed in two different ways. A well establish method [11] consists of subtraction of cocktail of background electrons from the inclusive electron spectrum. The cocktail is obtained by summing up contributions of electrons from light hadrons decays ($\pi^0$ Dalitz, $\rho$, $\eta$, $\omega$ and $\phi$ decays), photon conversion, direct radiation and electrons from decays of heavy quarkonia. The determination of the cocktail is obtained on the basis of the measured $\pi^0$ cross section. A second
method is based on the displacement of electrons from beauty with respect to the primary vertex thanks to the relatively large decay length of B mesons (cτ ~ 500 µm). A cut on the track impact parameter allows to select mainly decay electrons from beauty. The left panel of figure 1 shows

Figure 1. Left: Inclusive electron spectrum overlaid on the electron cocktail. Right: The heavy flavour electron spectrum is compared to the FONLL prediction.

the inclusive electron spectra after PID selection in the region 0.4 < p_T < 4 GeV/c, corrected for efficiency and acceptance. Unfolding was performed to account for p_T smearing due to Bremsstrahlung effects. The cocktail is shown in the same figure and is obtained adopting as input the π^0 cross section, measured by ALICE via the reconstruction of photon conversions and mt scaling for other light mesons (η, ω, φ, ρ). On the right panel, the heavy flavour spectrum is compared with FONLL predictions for charm and beauty summed together.

4. Cross section of forward single muons from heavy flavour decay
At forward rapidity heavy flavour production is studied using the single-muon p_T distribution measured with the ALICE muon spectrometer. The main sources of background for this analysis are: muons coming from in-flight decays of light hadrons (decay muons), muons from decay of hadrons produced in the absorber (secondary muons) and punch-through hadrons. Due to the lower mass of the parent particles, background muons have softer transverse momentum than muons from heavy flavour decays and dominate in the low p_T region. Punch-through hadrons are efficiently rejected by requiring that the track candidate in the tracking system has to be matched with the track reconstructed in the trigger system. In the region 2 < p_T < 6.5 GeV/c, simulation studies indicated that the contamination of secondary muons is about 3% and is therefore small. The contribution of decay muons at 25% level is the main background source and it is subtracted using Monte Carlo simulations using Pythia and PHOJET as event generators. The systematic error introduced by this procedure is found to range from 20 to 30% from high to low p_T. After background subtraction, the muon p_T spectrum is corrected for efficiency and normalized using the minimum bias pp production cross section found to be σ_{MB} = 62.3 ± 4.3 mb. Figure 2 shows the p_T differential cross section of single muons from heavy flavour decays in the p_T range 0.4 < p_T < 6.5 GeV/c and -4 < η < -2.5. The corresponding FONLL calculations agree, within the errors, with the experimental data points. With the improved alignment of the muon spectrometer and the full 2010 data sample, the p_T reach is expected to be extended to about 20 GeV/c. These improvements will allow the study of inclusive single muon production
cross section in the region $10 < p_T < 20 \text{ GeV}/c$, where the dominant contribution is coming from beauty decay. This will establish a reference for the study of the beauty quenching in Pb-Pb collisions at forward rapidities.

5. Cross section of D mesons in the central rapidity region

The study of open charm production via D meson hadronic decays is based on displaced vertex reconstruction and invariant mass analysis. The displaced vertex reconstruction, as stated in section 2, is achieved thanks to the excellent tracking system. The resolution on single track impact parameter with the 2010 data sample is close to the design value, being $70 \mu m$ at $p_T \sim 1 \text{ GeV}/c$, allowing selection of decay vertices of open charm mesons ($c\tau \sim 120 - 310 \mu m$) in the whole accessible $p_T$ region. Several D meson measurements are under study and among them, the most advanced are the $D^0$, the $D^{*+}$ and the $D^+$. The reconstruction of $D^0$ meson is performed using the hadronic channel $D^0 \rightarrow K^-\pi^+$ (BR = $(3.91 \pm 0.05)\%$) while the $D^{*+}$ meson

Figure 2. Comparison between the measured $d\sigma/dp_T$ distribution of single muons from heavy flavour decays in the rapidity range $-4 < \eta < -2.5$ and the FONLL predictions. The result corresponds to $\mathcal{L} = 3.49 \text{ nb}^{-1}$.

Figure 3. From left to right measured $d\sigma/dp_T$ for $D^0$, $D^+$ and $D^{*+}$ mesons in the central rapidity region ($|y| < 0.5$). Data are compared with predictions from FONLL and GM-VFNS. Results correspond to $\mathcal{L} = 1.6 \text{ nb}^{-1}$.
is reconstructed in the channel \( D^{+} \rightarrow D^{0} \pi^{+} \) (BR = (67.7±0.5)\%), where \( D^{0} \) is reconstructed using the \( K^{-}\pi^{+} \) channel. The \( D^{+} \) is reconstructed in the channel \( D^{+} \rightarrow K^{-}\pi^{+}\pi^{+} \) (BR = (9.22±0.21)\%). The selection strategy is based on three steps. At the beginning a series of quality requirements on single tracks (i.e. number of ITS clusters and TPC points) are applied. The acceptance for single tracks is \(|\eta|<0.8\). In the second step selections are applied to the topology of the decay taking advantage of the reconstruction on the secondary vertex. In the case of the \( D^{+} \), the secondary vertex cannot be reconstructed (being strong decay) and the selections are applied to the daughter \( D^{0} \). To further suppress the combinatorial background a selection based on PID information from TPC and TOF detectors is applied on the daughter tracks. The PID strategy is developed to retain close to 100\% of the signal so that the systematic on PID is kept under control. The raw yield extracted from the invariant mass analysis is then corrected for acceptance and efficiency. The efficiencies for prompt and secondary D mesons are accounted for. The contamination of D mesons from B decays is subtracted using a method based on FONLL expectation value for the b cross section. A systematic error \((p_{T} \) dependent), of the order of 15\%, is arising from such subtraction. The differential \( p_{T} \) production cross section in the central rapidity region is evaluated for each of the three mesons in the \( p_{T} \) range \([2-12] \) GeV/c and it is shown in figure 3. The results are obtained with \( \sim 20\% \) of the 2010 data sample. As clear from the invariant mass analysis in figure 4 there are good prospects to extend the \( p_{T} \) reach in the low and high region with the full 2010 data sample. Besides the aforementioned

\[ \text{Figure 4. } D^{+} \text{ signal in the } p_{T} \text{ range } [1,24] \text{ GeV/c extracted from } \sim 4.8 \text{ nb}^{-1}. \]

analysis, the \( D^{0} \rightarrow K^{-}\pi^{+}\pi^{-}\pi^{+} \) and the \( D_{s} \rightarrow K^{-}\bar{K}^{+}\pi^{+} \) analyses have allowed to extract promising signals in \( 4(5) \) \( p_{T} \) regions. Efficiency and acceptance correction studies are on going. Finally, the \( \Lambda_{c} \rightarrow pK^{-}\pi^{+} \) analysis already shows signals in different \( p_{T} \) bins. In this case the displaced vertex reconstruction is less effective than for D mesons since its proper decay length is only 59 \( \mu m \), although in the low \( p_{T} \) \((<3 \text{ GeV/c}) \) region it benefits from the excellent proton identification assured by TPC and TOF.
6. Cross section of inclusive $J/\psi$ production

The ALICE detector has the capability to measure the $J/\psi$ production in the central barrel and in the forward rapidity region with a $p_T$ acceptance down to 0. The analysis in the central barrel ($|y| < 0.9$) is performed in the di-electron channel ($e^+e^-$) while in the forward region ($-4 < y < -2.5$), it is performed in the dimuon channel. The $J/\psi \rightarrow e^+e^-$ analysis is carried out with a data sample of $2.4 \times 10^8$ MB events corresponding to an integrated luminosity of 3.9 nb$^{-1}$. Tracks were required to have a minimum $p_T$ of 1 GeV/c, at least one associated hit in the pixel detector and a minimum of 70 points in the TPC. Particle identification via specific energy loss in the TPC was applied. A total of $249 \pm 27(stat) \pm 20(syst)$ $J/\psi \rightarrow e^+e^-$ were detected.

The left panel of figure 5 shows the $d^2 \sigma_{J/\psi}/dp_T dy$ for the mid-rapidity range and for the forward rapidity data, compared with results from the other LHC experiments [12]. Right: ALICE preliminary $J/\psi$ production cross section compared to the result obtained by previous experiments at lower $\sqrt{s}$ [12]. See text for more details.

![Figure 5](image.png)

Figure 5. Left: $d^2 \sigma_{J/\psi}/dp_T dy$ for the mid-rapidity range and for the forward rapidity data, compared with results from the other LHC experiments [12]. Right: ALICE preliminary $J/\psi$ production cross section compared to the result obtained by previous experiments at lower $\sqrt{s}$ [12]. See text for more details.

In order to extract the cross section the raw yield was corrected for the acceptance and for trigger and reconstruction efficiency. The $d\sigma_{J/\psi}/dy$, compared with results from other LHC experiments, is shown in figure 6. The $p_T$-integrated inclusive $J/\psi$ production cross sections in pp collisions at $\sqrt{s} = 7$ TeV are: $\sigma_{J/\psi}(|y| < 0.9) = 10.8 \pm 1.2(stat) \pm 1.7(syst) \pm 1.6(pol)$ mb and $\sigma_{J/\psi}(2.5 < |y| < 4) = 6.31 \pm 0.25(stat) \pm 0.72(syst) \pm 0.95(pol)$ mb. The systematic error named $pol$ accounts for the unknown polarization of the $J/\psi$. Considering both the analyses ALICE has a broad coverage in rapidity and allows to measure $J/\psi$ down to $p_T = 0$ even in the central rapidity region.
Figure 6. $d\sigma_{J/\psi}/dy$ compared with results from other LHC experiments [12]. The error bars are the sum in quadrature of the statistical and systematic errors. The box represents the systematic uncertainty on luminosity.

7. Conclusions
The recent ALICE results on heavy flavour measurements in pp collisions at $\sqrt{s} = 7$ TeV have been reviewed in this paper. The production cross section of muons and electrons from heavy flavour decay, D mesons and $J/\psi$ were presented. Results agree, within uncertainties, with FONLL pQCD calculations. It was shown that the D mesons analysis, using the full 2010 data sample, can extend the $p_T$ reach of the measurement down to 1 GeV/$c$ or below.

8. References

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