Measurement of electrons from semi-leptonic heavy-flavour hadron decays in proton-proton and Pb–Pb collisions with ALICE at the LHC

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Abstract. Heavy quarks are produced in early partonic hard scatterings and experience the full history of a heavy-ion collision. Consequently heavy quarks are a good tool to study properties of the hot and dense medium. In proton-proton collisions, the study of the production of heavy quarks provides an important test for perturbative QCD and serves as a reference for heavy ion collisions. Heavy-flavour measurements in the semi-electronic channel are performed with ALICE at midrapidity. We present the measurement of the p_{T}-differential cross section in proton-proton collisions at $\sqrt{s} = 7$ TeV, and of the nuclear modification factor and elliptic flow in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV.

1. Introduction

The study of heavy-flavour production in proton-proton collisions serves as a good test for perturbative QCD calculations. In addition, it provides a reference for studies of heavy-ion collisions. Heavy quarks are produced in initial hard parton collisions and consequently are a good tool to study energy loss in the hot and dense medium. Due to the dead-cone effect [1], a mass ordering of the energy loss for different quark masses is expected, with the largest energy loss for the lightest quarks. The energy loss can be studied using the nuclear modification factor

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{\mathrm{dN^{PbPb}/dp_T}}{\mathrm{d\sigma^{pp}/dp_T}} \tag{1}$$

where $\langle T_{AA} \rangle$ is the nuclear overlap for a given centrality interval obtained via the Glauber model, $\mathrm{dN^{PbPb}/dp_T}$ is the yield measured in Pb–Pb collisions, and $\mathrm{d\sigma^{pp}/dp_T}$ is the cross section in proton-proton collisions. A study of the elliptic flow parameter v_2, defined as the second harmonic coefficient in the Fourier expansion of the azimuthal distribution of observed particles with respect to the reaction plane, could provide information on the thermalisation of heavy quarks in the hot and dense medium.

Measurements in the semi-electronic channels are well suited for heavy-flavour studies. Besides the large branching ratios of hadrons with heavy quarks into electrons ($\approx 10\%$), the electron channel allows for a measurement down to low transverse momentum p_{T}. Both charm and beauty-hadron decays contribute to the measured electron yield. These contributions can

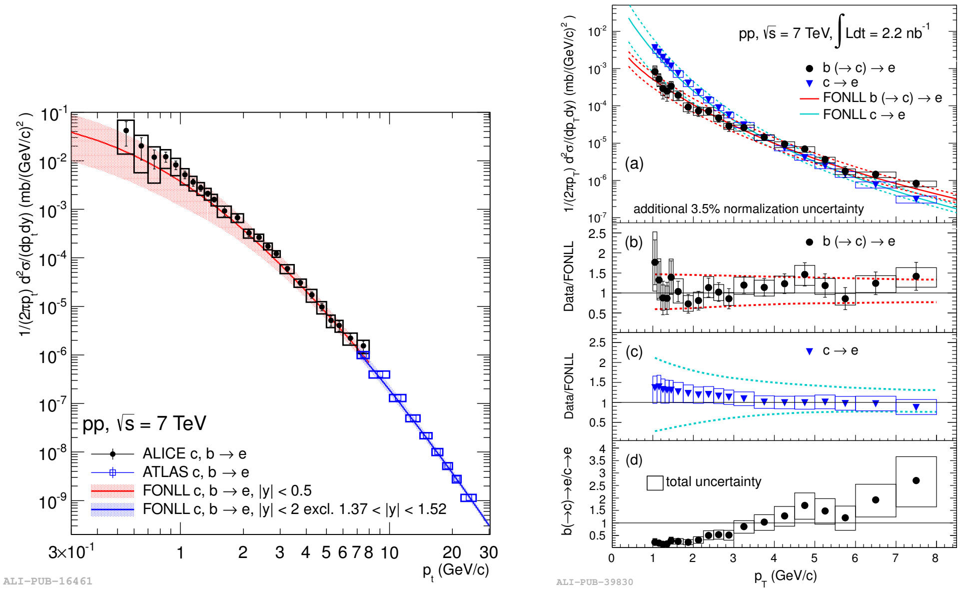

Figure 1. (Color online) Left: p_{T}-differential cross section of electrons from heavy-flavour hadron decays [2] from ALICE (dots) and ATLAS (open squares) [3]. Bands indicate a FONLL pQCD calculation. Right: p_{T}-differential cross section of electrons from beauty (black dots) and charm (blue triangles) hadron decays compared to a FONLL pQCD calculation [4]. The ratios of data over FONLL are shown for beauty in panel (b) and charm in panel (c). The ratio beauty to charm is shown in panel (d).

be disentangled even though the exact knowledge of the parent hadron kinematics is lost in the inclusive electron measurement.

The measurements are performed with ALICE, the dedicated heavy-ion experiment at the LHC, offering excellent particle identification capabilities. Various detectors are involved in the electron selection. A major device is the Time Projection Chamber (TPC), where the specific energy deposition ($\mathrm{d}E/\mathrm{d}x$) is used to distinguish electrons from other particles. At low p_{T} ($p_{\mathrm{T}} \leq 4$ GeV/c) the Time-of-Flight detector (TOF) is used to reject protons and kaons at momenta where they are indistinguishable from electrons in the TPC based on $\mathrm{d}E/\mathrm{d}x$ alone. At high p_{T} hadrons are suppressed further using additional rejection power from the Transition Radiation Detector (TRD) or the Electromagnetic Calorimeter (EMCal).

Apart from electrons from heavy-flavour hadron decays, the measured electron sample contains background from various sources: photon conversions including direct photons, Dalitz-decays of light mesons, and dielectron decays of vector mesons. Two methods are used to estimate the background. One method is to calculate the background from a cocktail of various sources, based on measured π^0 and η p_{T} spectra, and subtract this statistically from the electron sample. As a second method, the background from internal and in-material photon conversions can be reconstructed by combining the electron with other electron candidates and selecting pairs with a small invariant mass.

2. Measurements in proton-proton collisions

The p_{T}-differential cross section of electrons from heavy-flavour hadron decays, measured in proton-proton collisions at $\sqrt{s} = 7$ TeV at midrapidity ($|y| < 0.5$), is shown in Fig. 1 (left) [2]. The systematic uncertainty also includes the uncertainty of the background. The comparison with FONLL pQCD calculations [5, 6] shows a good agreement between theory and data. The

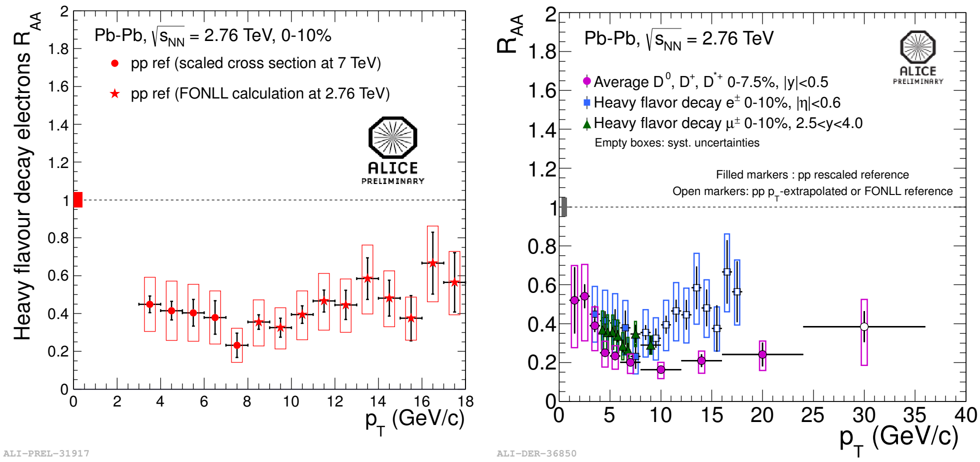

Figure 2. (Color online) Left: Nuclear modification factor of electrons from heavy-flavour hadron decays in the 0-10% most central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV [8]. Right: Comparison of the nuclear modification factors of electrons and muons, respectively, from semi-leptonic heavy-flavour hadron decays with the nuclear modification factor of D mesons [9].

p_T range covered by this measurement contains approximately 50% of the midrapidity charm cross section and approximately 90% of the midrapidity beauty cross section. The measurement, in combination with the results from the ATLAS Collaboration in the range 7 GeV/c < p_T < 26 GeV/c [3], can be used to test pQCD over a wide p_T range.

By selecting tracks with a large distance to the primary vertex in the transverse plane, the beauty component can be separated. The method exploits the longer lifetime of beauty hadrons ($c\tau \approx 500\ \mu$m) compared to charm hadrons ($c\tau \approx 100-300\ \mu$m). This method is complementary to the separation of electrons from beauty and charm hadron decays using angular correlations of electrons and hadrons, presented in [7]. Figure 1 (right) shows the p_T-differential cross section of electrons from beauty-hadron decays [4]. The measurement is well described by FONLL pQCD calculations. Close to p_T = 4 GeV/c the beauty component reaches the same cross section as the charm component.

3. Measurements in Pb–Pb collisions

The nuclear modification factor of electrons from heavy-flavour hadron decays is shown for 0-10% central collisions in Fig. 2 (left). The centrality class is determined using the VZERO detector. Below p_T < 8 GeV/c the proton-proton reference was obtained from the measured p_T-differential cross section at $\sqrt{s}$ = 7 TeV using a FONLL-based scaling [10], above 8 GeV/c the reference is the FONLL calculation. The FONLL scaling has been verified using the measurement in proton-proton collisions at $\sqrt{s}$ = 2.76 TeV. Since the FONLL scaled p_T-differential cross section currently has a smaller uncertainty than the measurement at the same energy, the scaled spectrum is used as a reference. A strong suppression of electrons from heavy-flavour hadron decays is seen in central Pb–Pb collisions. At low-p_T charm hadron decays are the main source of heavy-flavour decay electrons, while at high-p_T the beauty contribution becomes dominant. A similar suppression is seen in the semi-muonic channel at forward rapidity (Fig. 2 (right)) [11]. Considering the decay kinematics the suppression in the semi-electronic channels is also similar to the suppression of D mesons.

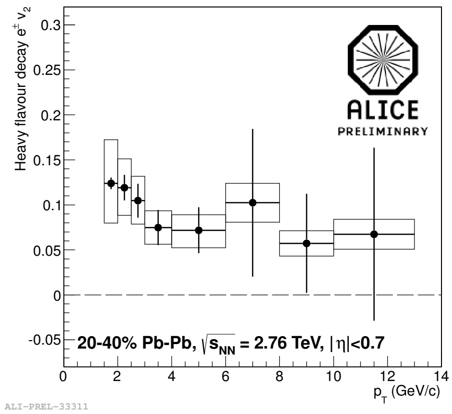

Figure 3. Elliptic flow parameter v_2 of electrons from heavy-flavour hadron decays in 20-40% semi-central collisions.

The elliptic flow parameter v_2 of electrons from heavy-flavour hadron decays is calculated via

$$v_2^{hfe} = \frac{(1+R)v_2^{incl} - v_2^{background}}{R} \tag{2}$$

where v_2^{incl} is the elliptic flow parameter of inclusive electrons, $v_2^{background}$ is the elliptic flow parameter of background electrons, and R is the signal-to-background ratio. The event plane is reconstructed using the VZERO detector. The elliptic flow parameter of background electrons is obtained using a cocktail based on the charged pion elliptic flow measurement and subtracted from the elliptic flow parameter of inclusive electrons.

Figure 3 shows the elliptic flow parameter of electrons from heavy-flavour hadron decays in 20-40% central Pb–Pb collisions. The systematic uncertainty contains both the uncertainty of the inclusive measurement and of the background. A non-zero elliptic flow parameter is observed.

4. Conclusions and Outlook

The measurement of the cross section of electrons from heavy-flavour hadron decays in proton-proton collisions at $\sqrt{s} = 7$ TeV was presented. Perturbative QCD calculations reproduce the data. Using electrons with a large distance to the primary vertex the cross section of electrons from beauty-hadron decays was extracted. In Pb–Pb collisions, a suppression was observed for electrons from heavy-flavour hadrons at high p_{T} in 0-10% central collisions. A non-zero elliptic flow might indicate that the heavy quarks thermalise with the hot and dense medium.

5. References

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