Measurement of electrons from heavy-flavour hadron decays in pp and p-Pb collisions with ALICE

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Abstract. ALICE measured electrons from inclusive heavy-flavour hadron decays and beauty-hadron decays at mid-rapidity in pp collisions at $\sqrt{s} = 7$ TeV and 2.76 TeV and p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. For both pp collision energies, p_{T}-differential electron production cross sections are presented and compared to pQCD predictions. For p-Pb collisions, the p_{T}-dependent nuclear modification factor of electrons from inclusive heavy-flavour hadron decays is presented.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Measurements of electrons from heavy-flavour hadron decays in pp collisions test perturbative QCD (pQCD) predictions and are references for Pb-Pb collisions, where heavy quarks are probes for in-medium energy loss [1]. Cold nuclear matter effects can be disentangled from hot-medium effects via measurements of heavy-flavour hadron decay electrons in p-Pb collisions [2].

The large branching ratio of semi-electronic charm and beauty-hadron decays ($\approx 10\%$) makes electron measurements an alternative to analyses of heavy-flavour production via reconstruction of exclusive hadronic decays. With the ALICE [3] experiment inner barrel detectors, electrons can be identified down to low transverse momenta p_{T}. Moreover, electrons from beauty-hadron decays can be measured separately, exploiting the spatial resolution provided by the ALICE Inner Tracking System (ITS) to select single electrons or secondary vertices with large displacements from the primary vertex. In addition, the ratio of electrons from beauty to those from inclusive heavy-flavour decays can be determined via azimuthal angular electron-hadron correlations.

2. Electron identification

All analyses of electrons from heavy-flavour hadron decays select a pure electron sample at mid-rapidity, using signals from the Time Projection Chamber (TPC) and from at least one of the devices Time of Flight (TOF), Electromagnetic Calorimeter (EMCal), and Transition Radiation Detector (TRD), with a track quality selection using ITS and TPC tracking information. TPC particle identification is based on energy deposition per unit of length, $\mathrm{d}E/\mathrm{d}x$, while TOF relates particle mass hypotheses to the time of flight and momentum p. The EMCal identifies electrons by their ratio $E/p \approx 1$, with the energy E deposited by an absorbed particle. Electron-hadron separation in the TRD uses a signal composed of the energy deposited by a charged particle in the TRD gas volume and the transition radiation emitted by electrons with $p \gtrsim 1$ GeV/c.

3. Additional requirements of beauty-hadron decay analyses

Kinematical differences between decays of B and D mesons can be used to identify electrons from beauty-hadron decays. Owing to the large decay length of B mesons ($c\tau \approx 500~\mu$m), their decay electron tracks and vertices are on average further displaced from the primary vertex than others. The ALICE ITS is well suited to detect this difference. Moreover, the reconstruction of simulated events shows that the near-side peak of azimuthal angular correlations between electrons from beauty decays and charged hadrons is about twice as wide as for charm decays. In ALICE, electrons from beauty-hadron decays were measured via three approaches:

- selection of electrons with a large transverse impact parameter to the primary vertex [4].
- reconstruction of electron-hadron vertices displaced from the primary vertex, with requirements on the invariant mass of the electron-hadron pair and on the hadron p_T.
- measurement of azimuthal angular correlations between electrons and charged hadrons. The near-side peak in the angular distribution around the electron track is fitted with PYTHIA templates for beauty and charm decays to determine their relative contribution.

4. Electron background subtraction and corrections

All selected electron samples contain electron background from non-heavy-flavour decays, which is subtracted by two alternative methods. In the first, p_T-differential non-heavy-flavour electron spectra are calculated based on hadron cross sections measured at the LHC. For the analyses of beauty decays via impact parameter and displaced secondary vertices, simulations determine the fraction of electron background remaining after all selection criteria. All measured spectra are corrected for detector acceptances and selection efficiencies and undergo an unfolding procedure to correct for bremsstrahlung effects and momentum smearing in the reconstruction.

The second background subtraction method is based on the identification of photonic electrons by reconstruction of $e^+ - e^-$ pairs with small invariant mass. The combinatorial background to this measurement is estimated via reconstruction of like-sign electron pairs and subtracted from the photonic electron yield. The resulting background is corrected for the pair-finding efficiency. This method is used in analyses of the relative beauty contributions to inclusive electron spectra from heavy-flavour hadron decays via electron-hadron correlations.

5. Results from proton-proton collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 2.76$ TeV

Fig. 1 shows measurements of heavy-flavour decay electrons in pp collisions at $\sqrt{s} = 7$ TeV. The left panel presents the p_T-differential electron cross section from heavy-flavour hadron decays for $0.5~\mathrm{GeV}/c < p_T < 8~\mathrm{GeV}/c$ in the rapidity range $|y| < 0.5$ [5]. In the middle and right panel, results from all three analyses of beauty decay electrons are summarized: the p_T-differential cross section determined by the impact parameter method is shown for $1~\mathrm{GeV}/c < p_T < 8~\mathrm{GeV}/c$ and $|y| < 0.8$ [4]. In comparison to the electron cross section from charm decays, calculated from ALICE measurements of charm-hadron cross sections, beauty decays become dominant for $p_T \gtrsim 4~\mathrm{GeV}/c$. The measurements of the p_T-differential cross section via displaced electron-hadron vertices and of the ratio $e(b)/e(b+c)$ of electrons from beauty to inclusive heavy-flavour decays via electron-hadron correlations, both for $|y| < 0.7$, are complementary to the first method. Their results are comparable and extend the p_T range of beauty decay measurements to 13 and 18 GeV/c, respectively. All spectra are described by pQCD predictions at fixed-order plus next-to-leading logarithms (FONLL [6]) within uncertainties. Predictions from the k_T-factorization [7] and GM-VFN scheme [8] achieve similarly good descriptions of the data.

At $\sqrt{s} = 2.76$ TeV, the reference energy for Pb-Pb collisions, the p_T-differential electron cross section from inclusive heavy-flavour hadron decays was measured for $2~\mathrm{GeV}/c < p_T < 12~\mathrm{GeV}/c$ and $|y| < 0.7$ (Fig. 2, left). For the same rapidity range, the ratio $e(b)/e(b+c)$ was determined via azimuthal angular electron-hadron correlations for $2.5~\mathrm{GeV}/c < p_T < 10~\mathrm{GeV}/c$ (Fig. 2,
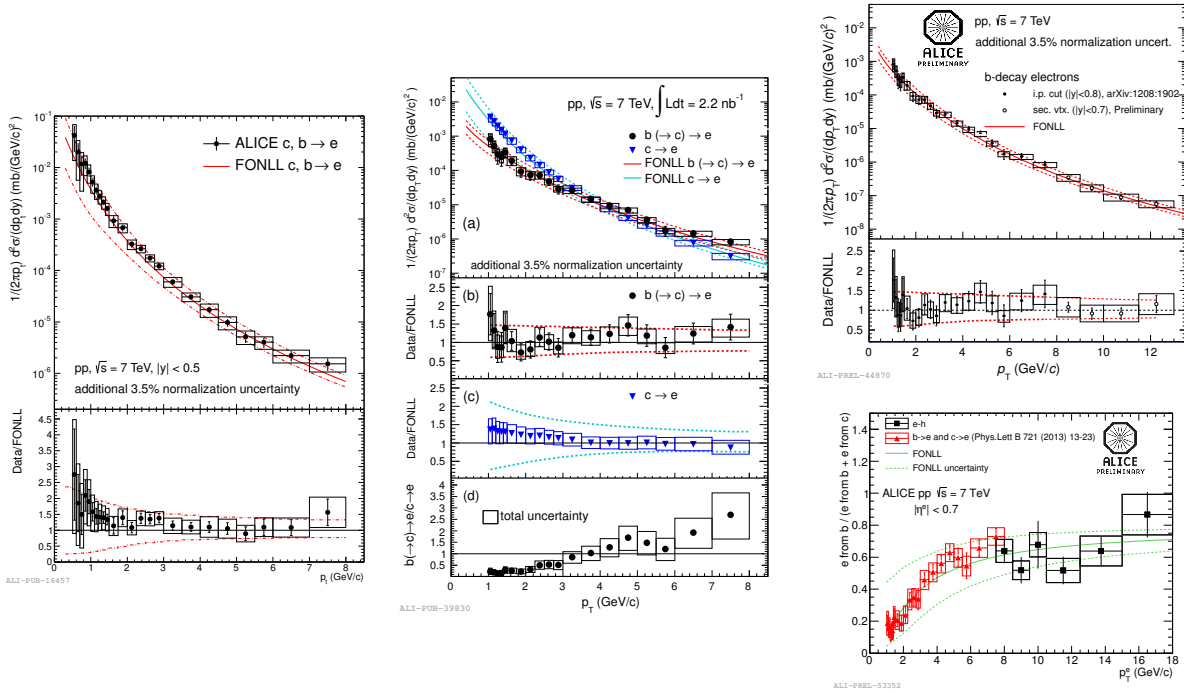
Figure 1. Electron cross section from inclusive heavy-flavour hadron decays [5] (left), beauty-hadron decays measured via impact parameter [4], and charm-hadron decays (middle) in pp collisions at $\sqrt{s} = 7$ TeV. Upper right: electron cross section from beauty-hadron decays from [4], with preliminary result of a measurement via displaced secondary vertices for $p_T > 8$ GeV/c. Lower right: ratio of electron yield from beauty-hadron decays to inclusive heavy-flavour hadron decays, measured via azimuthal angular electron-hadron correlations (black) and as ratio of results from middle and left panel (red). All results are compared to FONLL calculations [6].
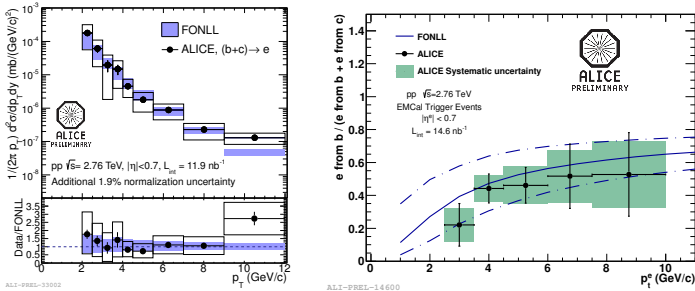

Figure 2. Electron cross section from heavy-flavour hadron decays (left) and ratio of electrons from beauty to inclusive heavy-flavour hadron decays (right) in pp collisions at $\sqrt{s} = 2.76$ TeV, compared to FONLL predictions [6].

right). All measurements are described by FONLL predictions [6], calculations from the k_T-factorization framework [7], and the GM-VFN scheme [8] within uncertainties.

6. Results from p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Inclusive heavy-flavour decay electrons were measured in p-Pb collisions for $-0.14 < y < 1.06$ via two electron identification methods: in the p_T range from 0.5 GeV/c to 6 GeV/c, TPC and TOF were utilized, while TPC and EMCal were used between 2 GeV/c and 12 GeV/c. The p_T-differential cross sections measured by both methods agree in the common range, where the TPC-TOF result has smaller uncertainties and is therefore considered for the preliminary result.

Fig. 3 shows the nuclear modification factor $R_{pPb}(p_T) = \frac{1}{\langle T_{pPb} \rangle} \frac{dN_{pPb}/dp_T}{d\sigma_{pp}/dp_T}$ for electrons from
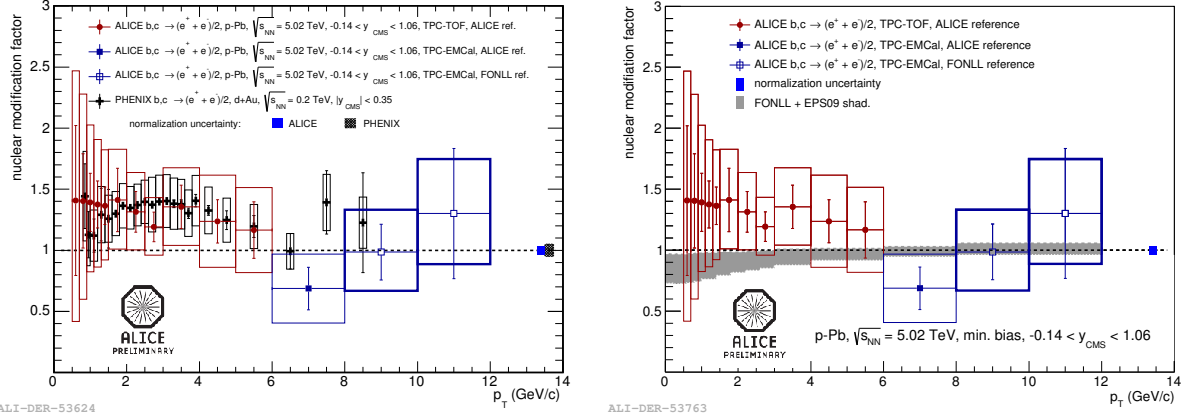
Figure 3. R_{pPb} of electrons from inclusive heavy-flavour decays, compared to PHENIX results from d-Au collisions at 0.2 TeV [9] (left) and EPS09 nuclear shadowing predictions [10] (right).

heavy-flavour hadron decays. $\langle T_{pPb} \rangle$ is the average nuclear overlap function, dN_{pPb}/dp_T the p_T-differential electron yield in p-Pb collisions, and $d\sigma_{pp}/dp_T$ the p_T-differential cross section in pp collisions. The electron spectrum in p-Pb collisions is compared to a pp reference spectrum that for $p_T < 8$ GeV/c is based on the result from pp collisions at $\sqrt{s} = 7$ TeV (see Fig. 1), scaled to $\sqrt{s} = 5.02$ TeV using FONLL calculations. At higher p_T, FONLL predictions were used as a reference. The p_T dependence of R_{pPb} is similar to the behaviour observed for non-photonic electrons at RHIC in d-Au collisions at $\sqrt{s_{NN}} = 0.2$ TeV [9] (Fig. 3, left), which showed an enhancement at intermediate p_T. However, the uncertainties of the ALICE measurements also allow for an agreement with predictions for the nuclear modification of the parton distribution functions from EPS09 parameterizations [10] that do not imply such an enhancement (Fig. 3, right). Future reductions of these uncertainties are expected from an improved pp reference, interpolating with measurements at $\sqrt{s} = 2.76$ TeV, and the usage of a TRD electron trigger.

7. Summary

ALICE measured the p_T-differential production cross sections of electrons from inclusive heavy-flavour and beauty-hadron decays at mid-rapidity for pp collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 2.76$ TeV. Results from three independent analyses of beauty-hadron decays are in mutual agreement. All measured cross sections from pp collisions are described by pQCD calculations within uncertainties. In p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, the p_T dependence of the nuclear modification factor of electrons from inclusive heavy-flavour hadron decays was determined. Within uncertainties, it agrees with the results from d-Au collisions at $\sqrt{s_{NN}} = 0.2$ TeV by the PHENIX collaboration and with EPS09 nuclear shadowing predictions.

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