NLO + Parton Shower Calculation of Heavy Flavour Electrons with Nuclear PDFs

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Abstract

Heavy flavour quarks (charm and beauty) are of special interest for the study of the Quark-Gluon Plasma as they are predominantly produced in the initial hard-scattering processes and participate in the entire evolution of the system. Thus, heavy flavours are an excellent probe to study in-medium energy loss and transport mechanisms in nuclear collisions by measuring, for instance, the nuclear modification factor R_{AA} or the azimuthal anisotropy and especially the elliptic flow v_2 of heavy-flavour particles.

Experimentally, heavy flavours are often investigated using measurements of electrons from heavy-flavour hadron decays. These electrons can be separated statistically from the background and provide insight into the colour charge (quark vs. gluon) and mass (light quarks vs. charm vs. beauty) dependence of parton energy loss.

In this poster, we present the relative contribution of electrons from beauty hadron decays to the yield of electrons from heavy-flavour hadron decays estimated with Monte Carlo simulations based on POWHEG at $\sqrt{s_{NN}} = 2.76$ TeV. Nuclear effects are taken into account using the nuclear parton distribution functions EPS09 and nCTEQ15.

Motivation

- The POWHEG BOX heavy quark package [1, 2] provides exclusive final states with next-to-leading order (NLO) accuracy in the hard process. Thus, this method can be further employed to study heavy-flavour production mechanisms, correlations etc.
- The results can improve our understanding of cold nuclear matter effects due to nuclear parton distribution functions (PDFs) and help to separate them from final-state medium effects.
- Our calculations provide one essential ingredient to separate the contributions of charm and beauty quarks in the measurement of the p_T-differential invariant cross section and elliptic flow (v_2) of electrons from heavy-flavour hadron decays:

$$v_2^{b\to e} = \frac{v_2^{c,b\to e} - (1-R)v_2^{c\to e}}{R},$$

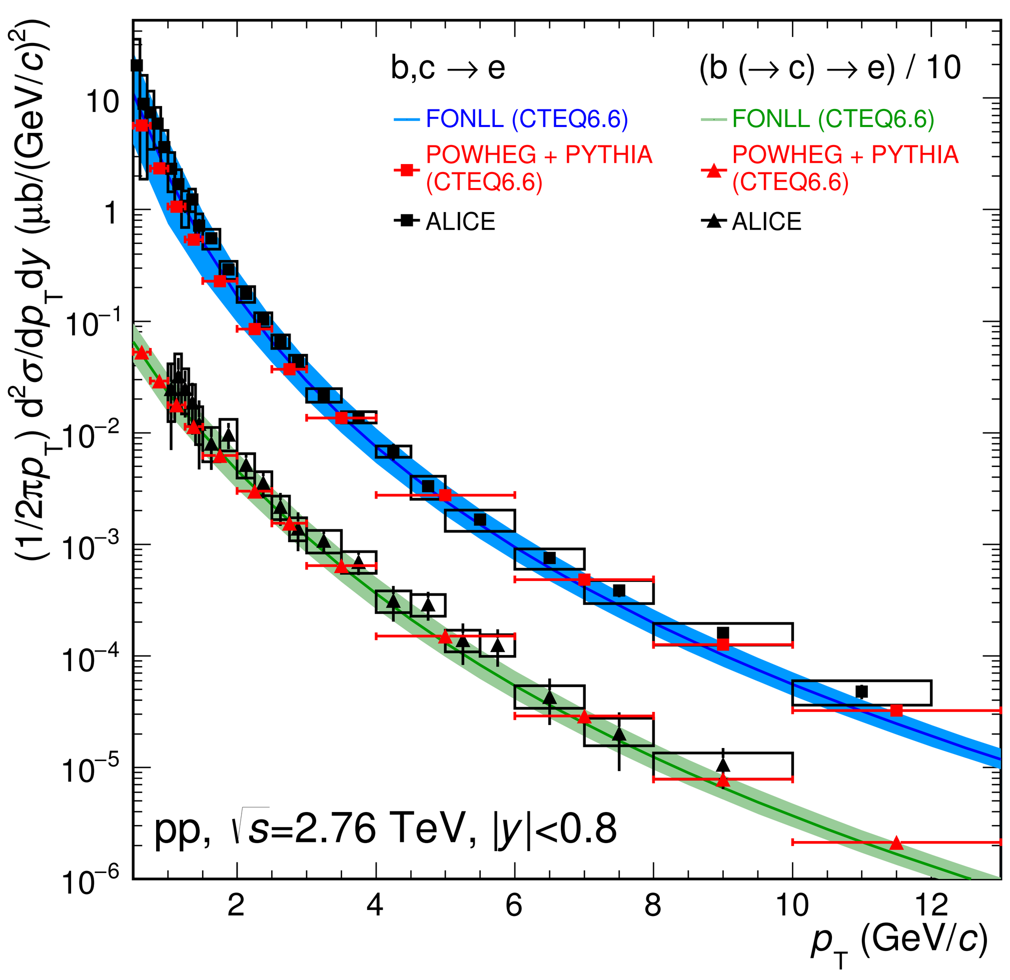
where R is the relative contribution of electrons from beauty hadron decays to the yield of heavy-flavour hadron decays

$$R = \frac{b\,(\to c) \to e}{b,c \to e}.$$

Method

- Leading order (LO) calculations are an inadequate estimator of heavy-flavour production due to new processes occurring at next-to-leading order (NLO) which give rise to large and different K factors for beauty and charm production.
- The NLO heavy-flavour production provided by POWHEG can be matched to shower Monte Carlos. We matched POWHEG to PYTHIA 8, which provides the showering, hadronisation and decay for the electrons from heavy-flavour hadron decays.
- We used an equal factorization and renormalization scale $\mu_f = \mu_r = \sqrt{p_T^2 + m_Q^2}$ and the heavy quark masses $m_b = 4.75\,\text{GeV}$ and $m_c = 1.5\,\text{GeV}$.
- Nuclear effects are considered using nuclear parton distribution functions (PDFs) like EPS09 and nCTEQ15.
- Only the central results are shown. Be aware of overall uncertainties coming from the choice of scale, masses, parton distribution functions (PDFs), matching schemes etc.
- Both particles and antiparticles are considered: $(e^+ + e^-)/2$.

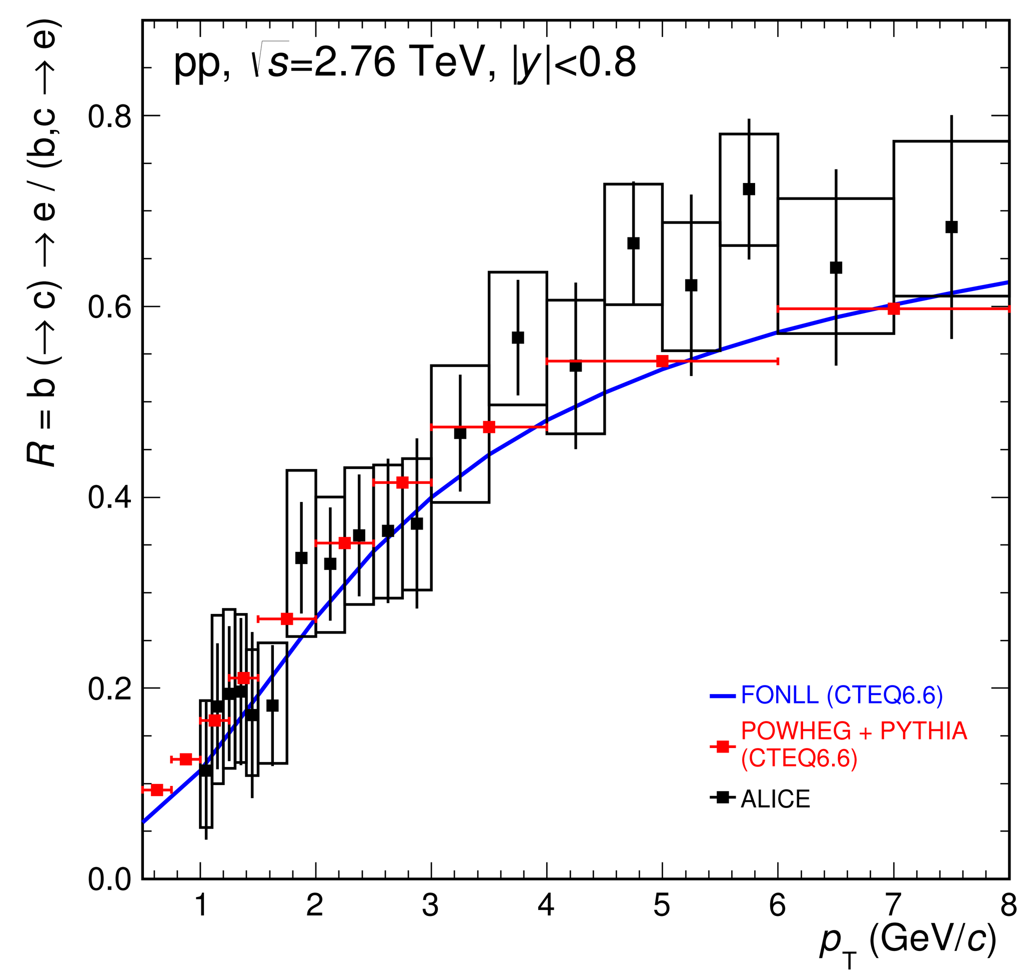
Results for pp collisions at $\sqrt{s} = 2.76$ TeV



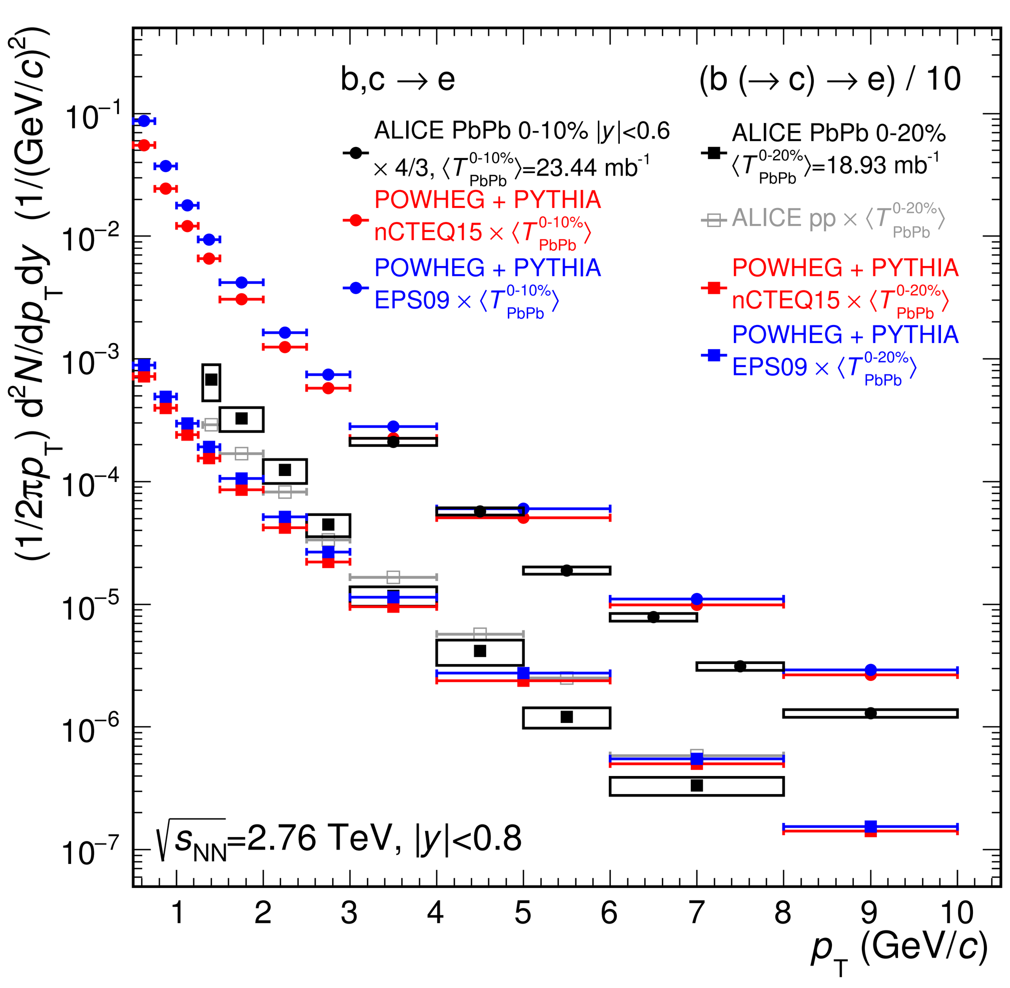
- The POWHEG+PYTHIA calculations show good agreement to the FONLL results, which are expected to be more accurate at large p_T, but provide only inclusive particle distributions.
- Both POWHEG+PYTHIA and FONLL show good agreement with ALICE data but tend to understimate them at large p_T, especially for electrons from beauty hadron decays.
- However, the POWHEG+PYTHIA calculations are in overall agreement with the ALICE data within the uncertainties.

Left: Invariant cross section of electrons from beauty hadron decays (divided by ten) and from heavy-flavour hadron decays calculated using POWHEG+PYTHIA using proton PDFs (CTEQ6.6). In addition, ALICE data from pp collisions at $\sqrt{s} = 2.76$ TeV [3, 4] and theoretical predictions from FONLL including scale, mass and PDF uncertainties are shown.

Right: Relative contribution of electrons from beauty hadron decays to the yield of electrons from heavy-flavour hadron decays calculated with POWHEG+PYTHIA using proton PDFs (CTEQ6.6). In addition, ALICE data from pp collisions at $\sqrt{s} = 2.76$ TeV [4] and the central prediction from FONLL are shown.



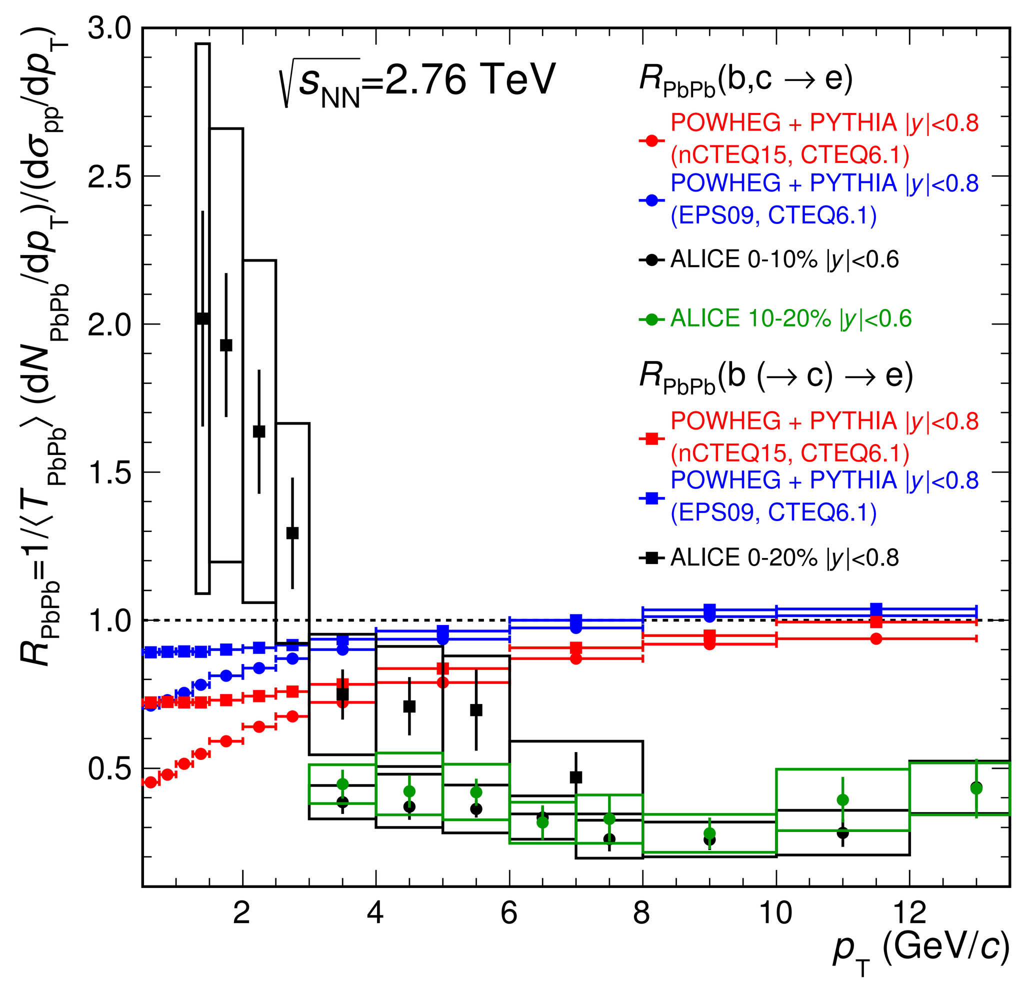
Results for Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV



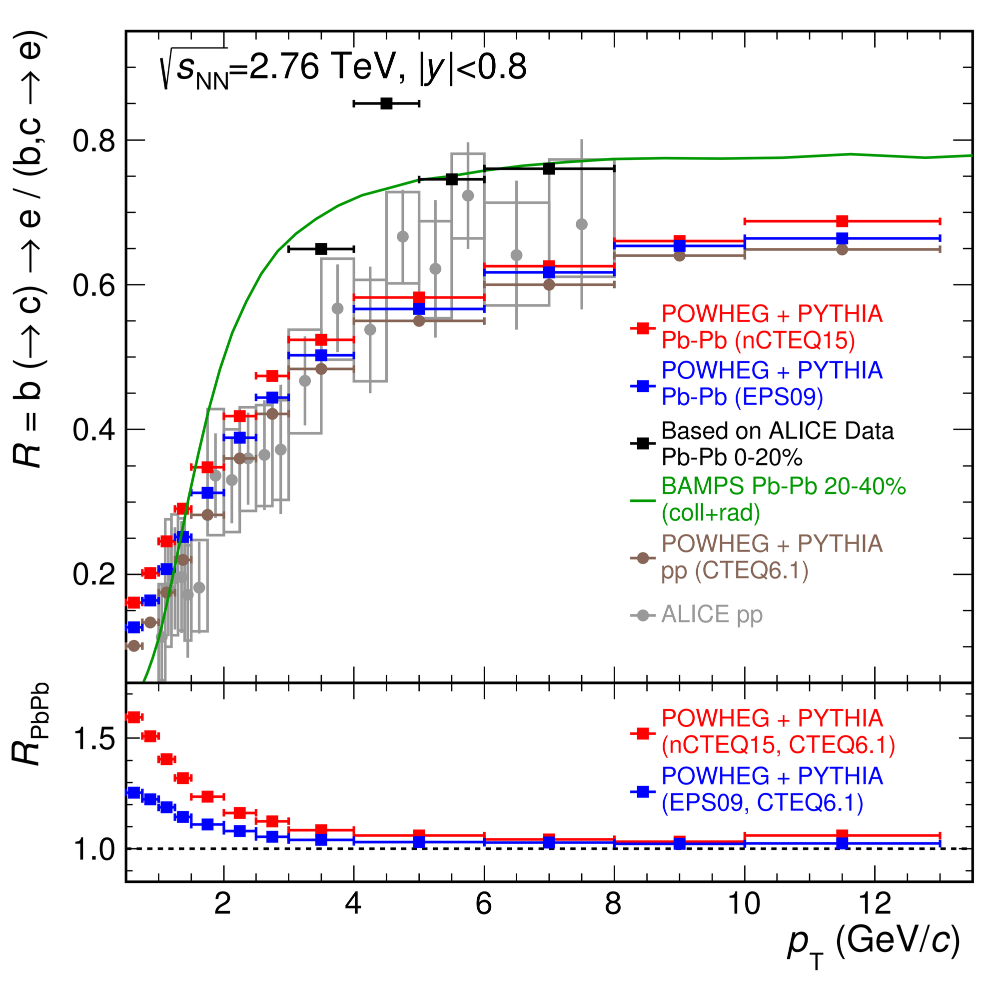
- The POWHEG+PYTHIA results using nuclear PDFs show a stronger suppression for charm than for beauty contributions as they probe the PDFs to lower Bjorken x and are thus stronger affected by gluon shadowing.
- The central results for the nuclear PDFs differ notably. The yield of the nCTEQ15 calculations is always below the EPS09 results leading to a larger nuclear modification. This is explained by an enhanced gluon shadowing in nCTEQ15 and points to an option to further restrict the gluon density at low x.
- The modification of the electron spectrum due to nuclear PDFs vanishes with increasing p_T as shown by the R_{PbPb}. Thus, the Monte Carlo data for nuclear PDFs are not able to describe central ALICE Pb–Pb data and stress the significance of final-state effects.

Left: Yield of electrons from beauty (divided by ten) and from heavy-flavour hadron decays calculated using POWHEG+PYTHIA using the nuclear PDFs EPS09 and nCTEQ15. In addition, the ALICE data at $\sqrt{s_{NN}} = 2.76$ TeV for total heavy-flavour contributions in $0-10\%$ central Pb–Pb collisions in $|y| < 0.6$ [5] (scaled by 4/3 to account for the different rapidity range) and the beauty contributions for $0-20\%$ central Pb–Pb collisions [6] as well as for pp collision [3] are shown. The Monte Carlo and pp results are scaled to the Pb–Pb results using the average nuclear overlap $\langle T_{PbPb} \rangle$.

Right: Nuclear modification factor R_{PbPb} for electrons from heavy-flavour hadron decays and from beauty hadron decays calculated with POWHEG+PYTHIA for EPS09 and nCTEQ15 nuclear PDFs relative to CTEQ6.1. In addition, the ALICE nuclear modification factor for the combined contributions at $0-10\%$ and $10-20\%$ central Pb–Pb collisions [5] and for beauty contributions at $0-20\%$ central Pb–Pb collisions [6] at $\sqrt{s_{NN}} = 2.76$ TeV are shown.



Results for Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV (cont.)



- The relative yield R of electrons from beauty-hadron decays to the the yield of electrons from heavy-flavour hadron decays in Pb–Pb collisions shows a small increase in contrast to pp collisions due to the use of nuclear PDFs, but these effects vanish with increasing p_T.
- Since final-state effects have been neglected, these calculations give only an impression of the cold nuclear matter effects involved in nuclear collisions.
- The ratio calculate from ALICE data is enhanced with respect to the pp and POWHEG+PYTHIA results, which is explained by medium effect and is consistent with the theoretical expectation that charm contributions are stronger suppressed than beauty contributions (mass hierarchy).
- The BAMPS result – which includes final-state medium interactions (collisional and radiational) – qualitatively agrees with the ratio based on ALICE data though it is derived for a different centrality.

Left: Relative contribution of electrons from beauty-hadron decays to the yield of electrons form heavy-flavour hadron decays calculated with POWHEG+PYTHIA using nuclear PDFs EPS09 and nCTEQ15 as well as proton PDFs CTEQ6.1. In addition, a ratio derived from ALICE data in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [6, 5], the ALICE pp results at $\sqrt{s} = 2.76$ TeV [3] and BAMPS results [7] are shown.

CONCLUSIONS

- Exclusive final-state calculations of electrons from heavy-flavour hadron decays using POWHEG+PYTHIA show **good agreement with inclusive predictions provided by FONLL and pp data from ALICE** at $\sqrt{s} = 2.76$ TeV.
- The calculated relative contributions from electrons from beauty hadron decays to electrons from heavy-flavour hadron decays in Pb–Pb collisions can be used as a first estimator of the true ratio, which will of course be enhanced by medium effects.
- Calculations of Pb–Pb collisions with **nuclear PDFs are not able to describe central** ($0-20\%$) **Pb–Pb data of ALICE** at $\sqrt{s_{NN}} = 2.76$ TeV due to final-state effects. **Modifications due to nuclear PDFs are significant at low p_T.**
- The results obtained with the two prominent nuclear PDFs **EPS09 and nCTEQ15 show a qualitatively similar behavior**. However, the central **nCTEQ15 results have a lower yield and stronger suppression of heavy-flavour electrons** due to a stronger gluon shadowing. The nuclear modification of the electron spectrum at low p_T suggests **a possibility to further restrict the low x gluon density**.

References:

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[5] ALICE, J. Adam *et al.*, (2016), arXiv:1609.07104.
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