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

Florian Herrmann

Institut für Kernphysik, Universität Münster, Germany

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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 heavy-flavour electrons (HFE) 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 for different collision systems at $\sqrt{s_{NN}} = 2.76$ TeV and $\sqrt{s_{NN}} = 5.02$ TeV. Nuclear effects are taken into account using the nuclear parton distribution functions EPS09, EPPS16 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:

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

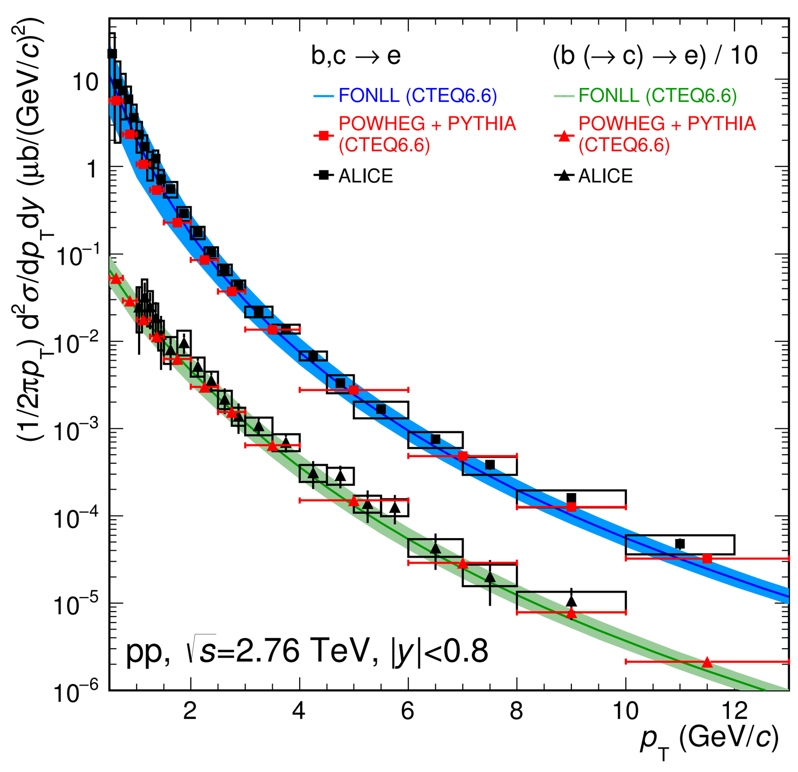
where R is the relative contribution of electrons from beauty hadron decays to the yield of heavy-flavour hadron decays

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

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, EPPS16 and nCTEQ15.
- Both particles and antiparticles are considered: $(e^+ + e^-)/2$.

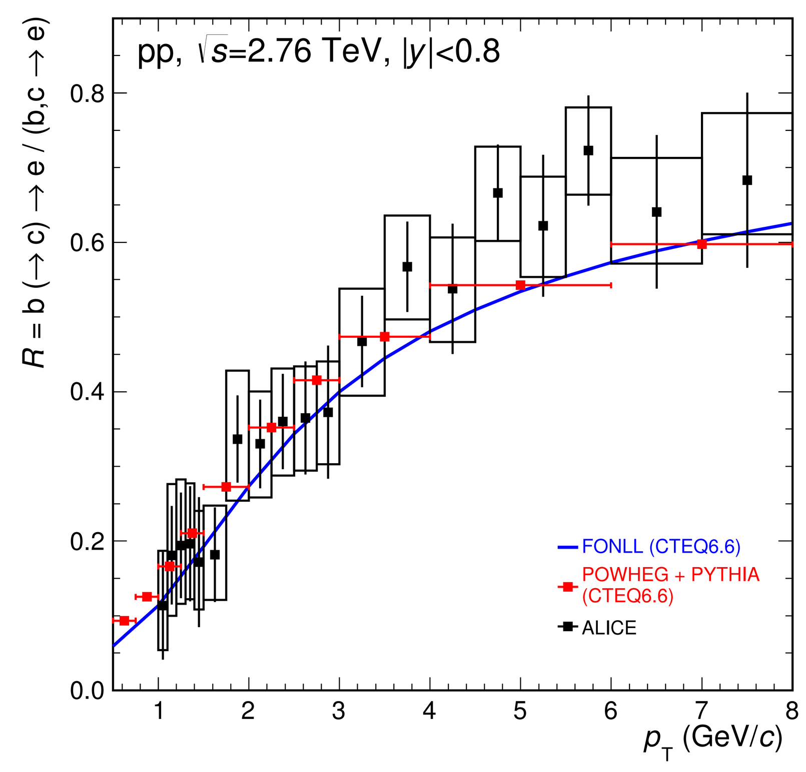
Results for pp collisions at $\sqrt{s} = 2.76$ TeV



- The POWHEG+PYTHIA calculations show good agreement to the FONLL (Fixed-Order Next-to-Leading Logarithm) 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 underestimate them at low and 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.

Fig. 1, 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 [3, 4] and theoretical predictions from FONLL including scale, mass and PDF uncertainties are shown.

Fig. 2, 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 [4] and the central prediction from FONLL are shown.



Results for p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

- The POWHEG+PYTHIA results using nuclear PDFs are not able to describe the measured spectrum of HFEs at low p_T, but converge with them at large p_T (Fig. 3). However, large scale uncertainties are expected for the theoretical predictions.
- The nuclear modification predicted by the nPDFs with respect to their proton baseline shows a suppression at low p_T which is only in rough agreement with data (Fig. 4).
- The central results for the nuclear PDFs differ. The yield of the nCTEQ15 calculations is always below the EPS09 and EPPS16 results leading to a larger nuclear modification. This is explained by an enhanced gluon shadowing in nCTEQ15 (Fig. 5) and points to an option to further restrict the gluon density at low x.
- The relative yield R of electrons from beauty hadron decays to the total yield of HFEs in p–Pb collisions shows a small increase in contrast to pp collisions due to the use of nuclear PDFs (Fig. 6), but these effects vanish with increasing p_T.
- This increase is due to a stronger suppression for charm than for beauty contributions as they probe the nPDFs to lower Bjorken x and are thus stronger affected by gluon shadowing (Fig. 5).

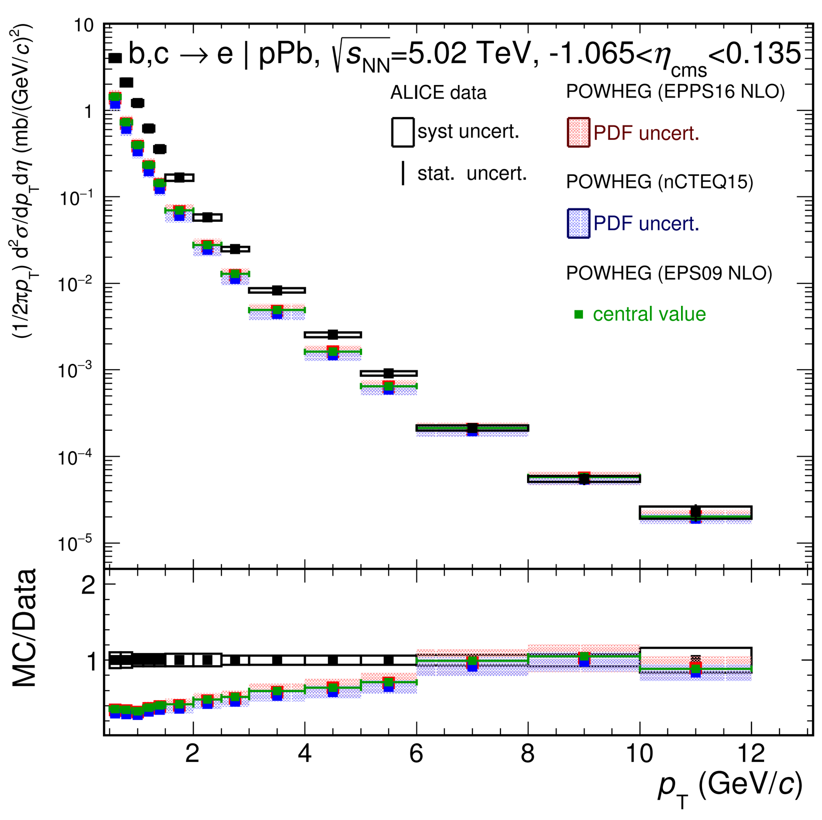


Fig. 3: HFE spectrum calculated with POWHEG+PYTHIA using the nuclear PDFs EPPS16, EPS09 and nCTEQ15. In addition, ALICE [5] data are shown.

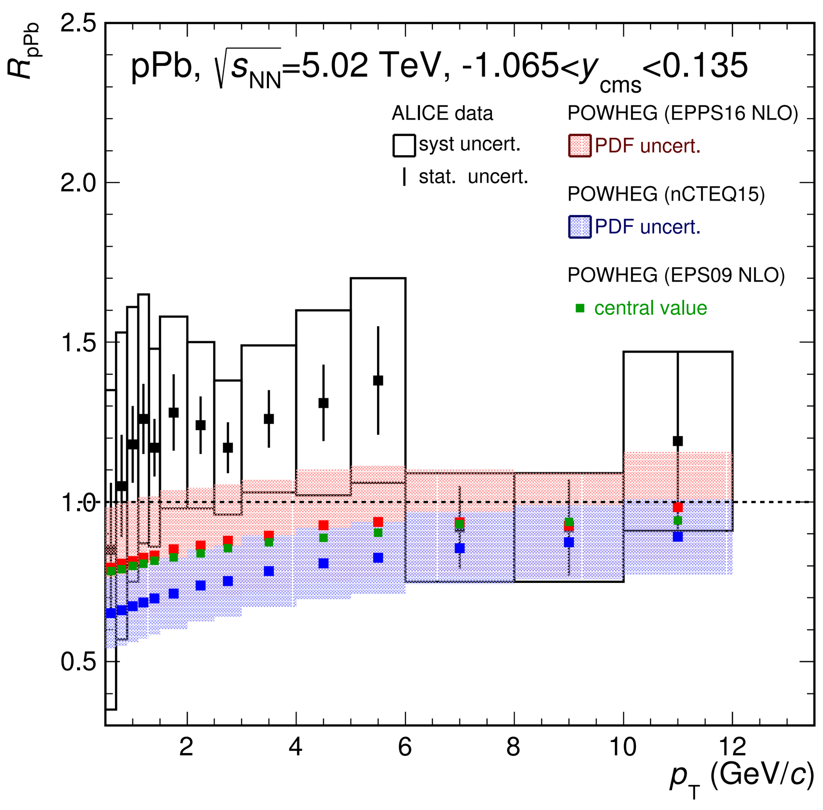


Fig. 4: Nuclear modification R_{pPb} of HFEs calculated with POWHEG+PYTHIA using the nuclear PDFs EPPS16, EPS09 and nCTEQ15 and their respective proton baselines. In addition, ALICE [5] data are shown.

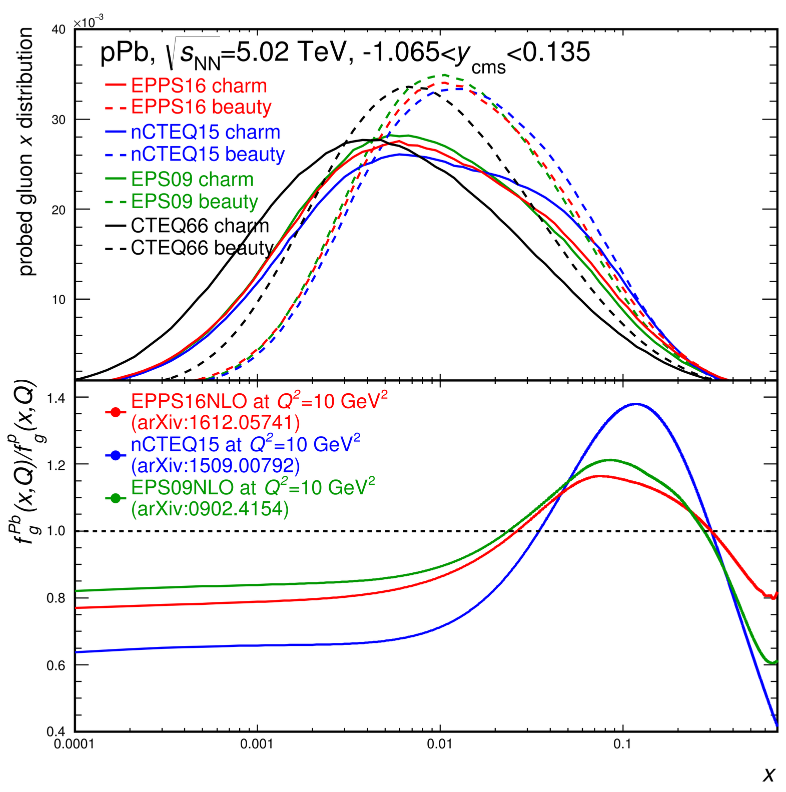


Fig. 5: Actual probed gluon densities of the Pb nuclei (normalized to 1) and nuclear modification of gluon densities (shadowing) at $Q^2 = 10\,\text{GeV}^2$ as a function of Bjorken x.

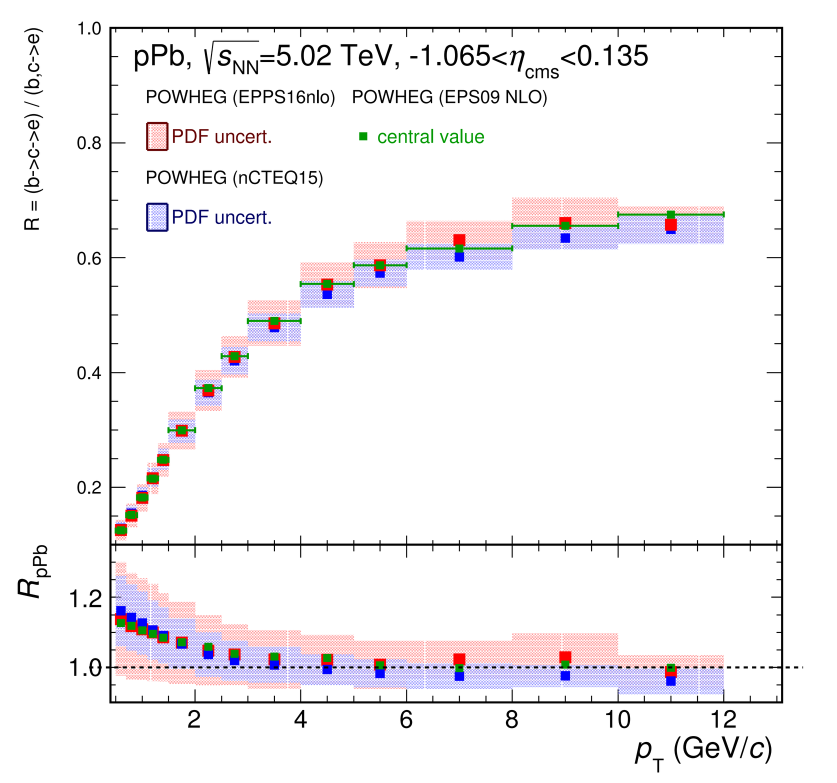


Fig. 6: Relative contribution of electrons from beauty hadron decays to the total yield of electrons from HFEs and its nuclear modification R_{pPb} calculated with POWHEG+PYTHIA using nPDFs.

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

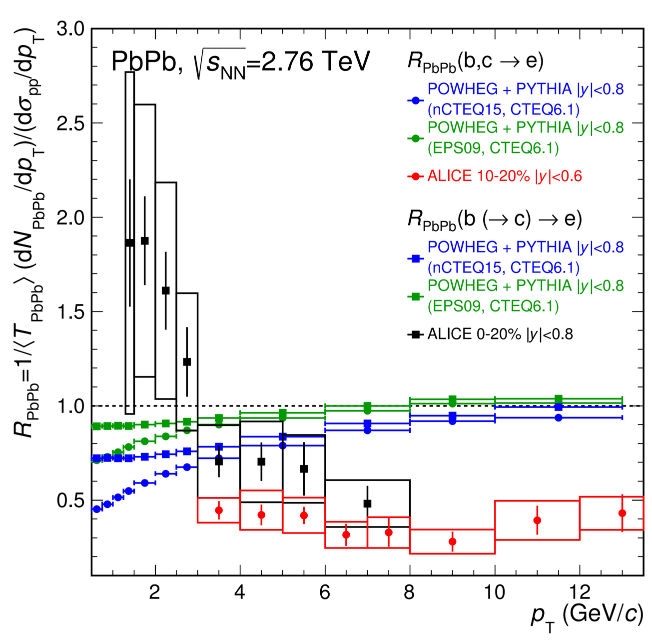


Fig. 7: Nuclear modification factor R_{PbPb} for HFE and HFE from beauty hadron decays calculated with POWHEG+PYTHIA and nPDFs relative to their respective proton baseline. In addition, the ALICE nuclear modification factor for the combined contributions at $0-10\%$ central Pb–Pb collisions [6] and for beauty contributions at $0-20\%$ central Pb–Pb collisions [7] are shown.

- The nuclear modifications predicted by the nPDFs are qualitatively similar to the p–Pb results, but significantly enhanced.
- 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.
- Since final-state effects have been neglected, these calculations give only an impression of the cold nuclear matter effects involved in nuclear collisions.
- The BAMPS result – which includes final-state medium interactions (collisional and radiational) – is enhanced with respect to the pp and POWHEG+PYTHIA results, which is explained by medium effects and is consistent with the theoretical expectation that charm contributions are stronger suppressed than beauty contributions (mass hierarchy).

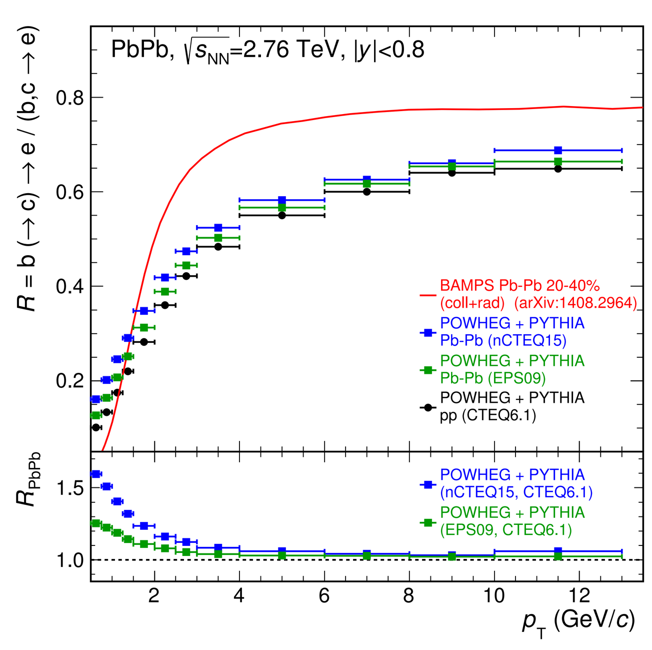


Fig. 8: Relative contribution of electrons from beauty hadron decays to the yield of electrons from heavy-flavour hadron decays calculated with POWHEG+PYTHIA using nuclear PDFs EPS09 and nCTEQ15 as well as proton PDFs CTEQ6.1. In addition, the BAMPS predictions [8] are shown.

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 nPDF calculations can only **roughly describe the measured p–Pb data** at $\sqrt{s_{NN}} = 5.02$ TeV and show different shadowing behaviour.
- Predictions for 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 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. The ratio **can be used to estimate and disentangle elliptic flow from beauty (paper on arXiv:1705.00161).**
- The results obtained with the most prominent nuclear PDFs **EPS09, EPPS16 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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[6] ALICE, J. Adam *et al.*, (2016), arXiv:1609.07104.

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Contact:

Florian Herrmann
Institut für Kernphysik
Universität Münster, Germany
E-mail: f.herrmann@cern.ch