LO and NLO Calculations of Heavy Flavour Electron Correlations in Small Systems

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Quark Matter 2018

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 initial hard-scattering processes and participate in the entire evolution of the system. Moreover, heavy flavour production is well under control of perturbative QCD. Thus, heavy flavours are an excellent probe to study pQCD in small systems as well as parton in-medium energy loss and transport mechanisms in nuclear collisions by measuring, for instance, the cross section, angular correlations or the nuclear modification factor R_{AA}. Experimentally, heavy flavours are often investigated via measurements of electrons from heavy-flavour hadron decays. These electrons can be separated statistically from the background and their angular correlations with other heavy flavour electrons or with charged particles can be studied. In this poster, we present theoretical predictions for the spectrum and angular correlations of heavy flavour electrons in pp collisions at $\sqrt{s} = 13$ TeV obtained at LO and NLO accuracy using PYTHIA and POWHEG, respectively. The correlations can be utilized to separate charm and beauty contributions and provide insights into different heavy flavour production mechanisms.

Motivation

- Electrons from heavy-flavour hadron decays (HFE: Heavy flavour electrons) and their correlations can test pQCD and improve Monte Carlo (MC) predictions.
- Two-particle correlations can be used to disentangle charm and beauty contributions and are also sensitive to production mechanisms and multiparton interactions (MPI).
- A solid understanding of these impacts helps to improve our interpretation of:
  - cold nuclear matter effects (e.g. nuclear PDFs, multiparton interactions),
  - hot nuclear matter effects (e.g. energy loss mechanism).

Method

- Simple leading order (LO) calculations ($q\bar{q}/gg \rightarrow Q\bar{Q}$) 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
- LO MC generators like PYTHIA 8 [1, 2] approximate these higher order contributions via so called flavour excitations (e.g. $Qg \rightarrow Qg$) and gluon splittings
- NLO generators like POWHEG [3, 4] provide exclusive final states and can be matched to shower MC generators, but MC tunes or the multiparton interaction framework are not that elaborated for NLO predictions

⇒ Cross checks with inclusive tools (FONLL [5, 6]) and between exclusive MC predictions are required

Common Settings

- $\mu_f = \mu_r = \sqrt{p_T^2 + m_Q^2}$, $m_b = 4.75\,\text{GeV}$ and $m_c = 1.5\,\text{GeV}$
- Both particles and antiparticles are considered: $(e^+ + e^-)/2$

PYTHIA 8

- Minimum bias events, Monash 2013 tune (pdf: NNPDF2.3QED LO)

POWHEG HVQ

- pdf: NNPDF2.3QED NLO; matched to PYTHIA 8, for showering, hadronisation and decay

FONLL

- pdf: NNPDF3.0 NLO

HFE spectrum, fraction of beauty, correlations for pp at $\sqrt{s} = 13$ TeV

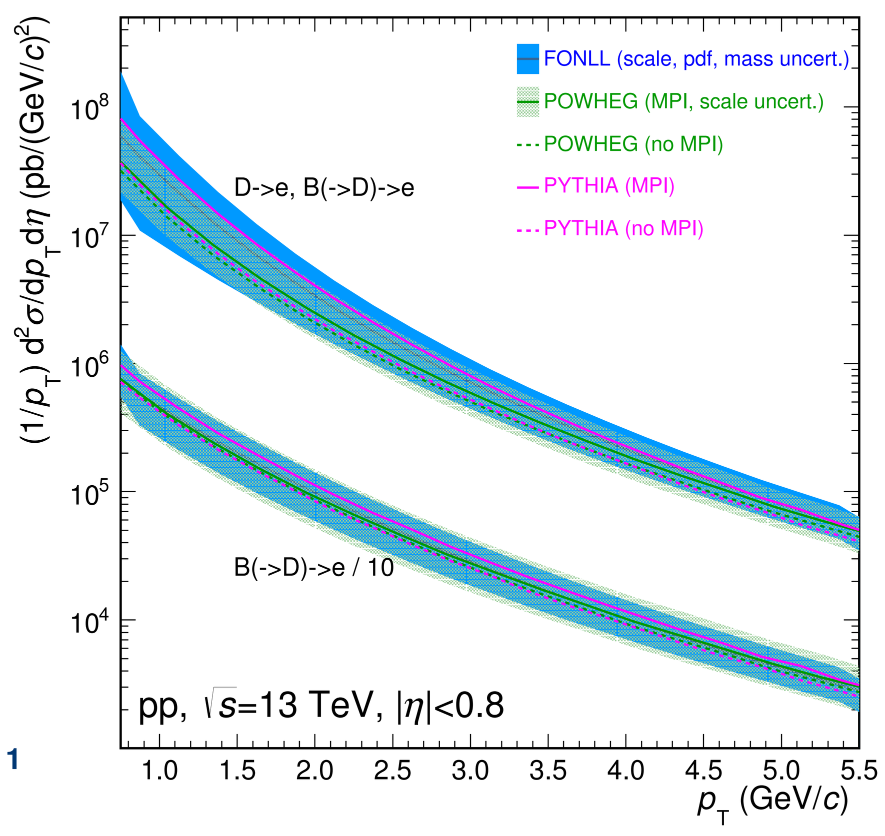


Fig. 1

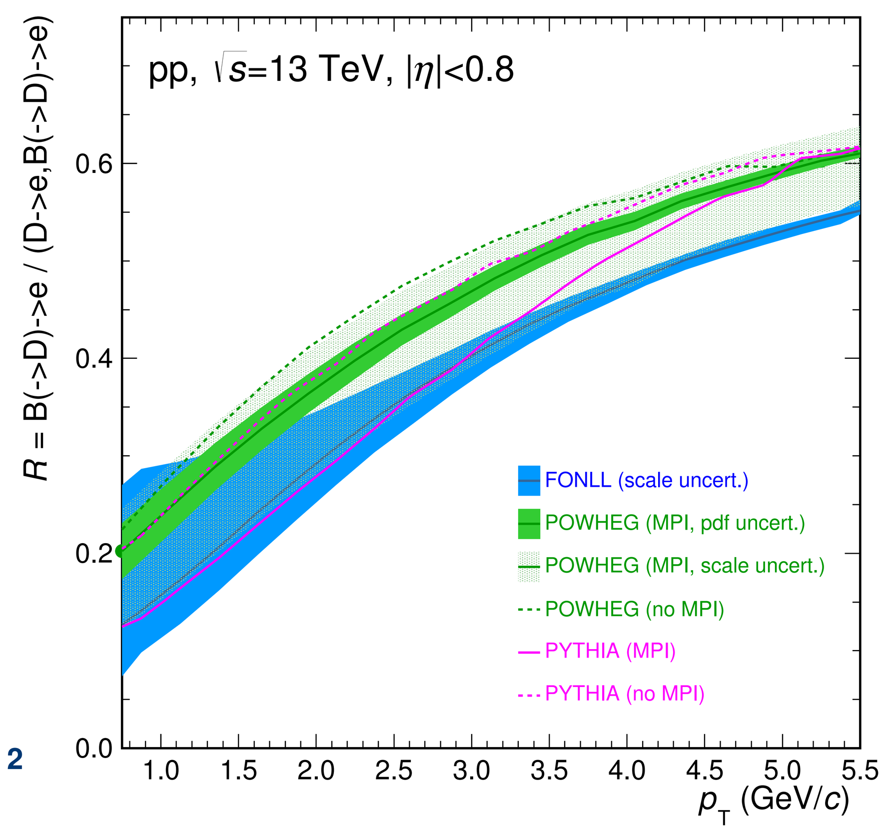


Fig. 2

- The HFE spectra (Fig. 1) are consistent within the uncertainties (the POWHEG scale variation for charm is restricted to $\mu >= \mu_{\text{default}}$).
- For comparison, also the results without multiparton interactions (MPI) are shown, which have a stronger effect in PYTHIA (minimum bias production) than in POWHEG (heavy quark production) calculations.
- In the fraction of beauty contributions (Fig. 2) uncertainties partially cancel, but the theoretical predictions are only in rough agreement (→ to be investigated).

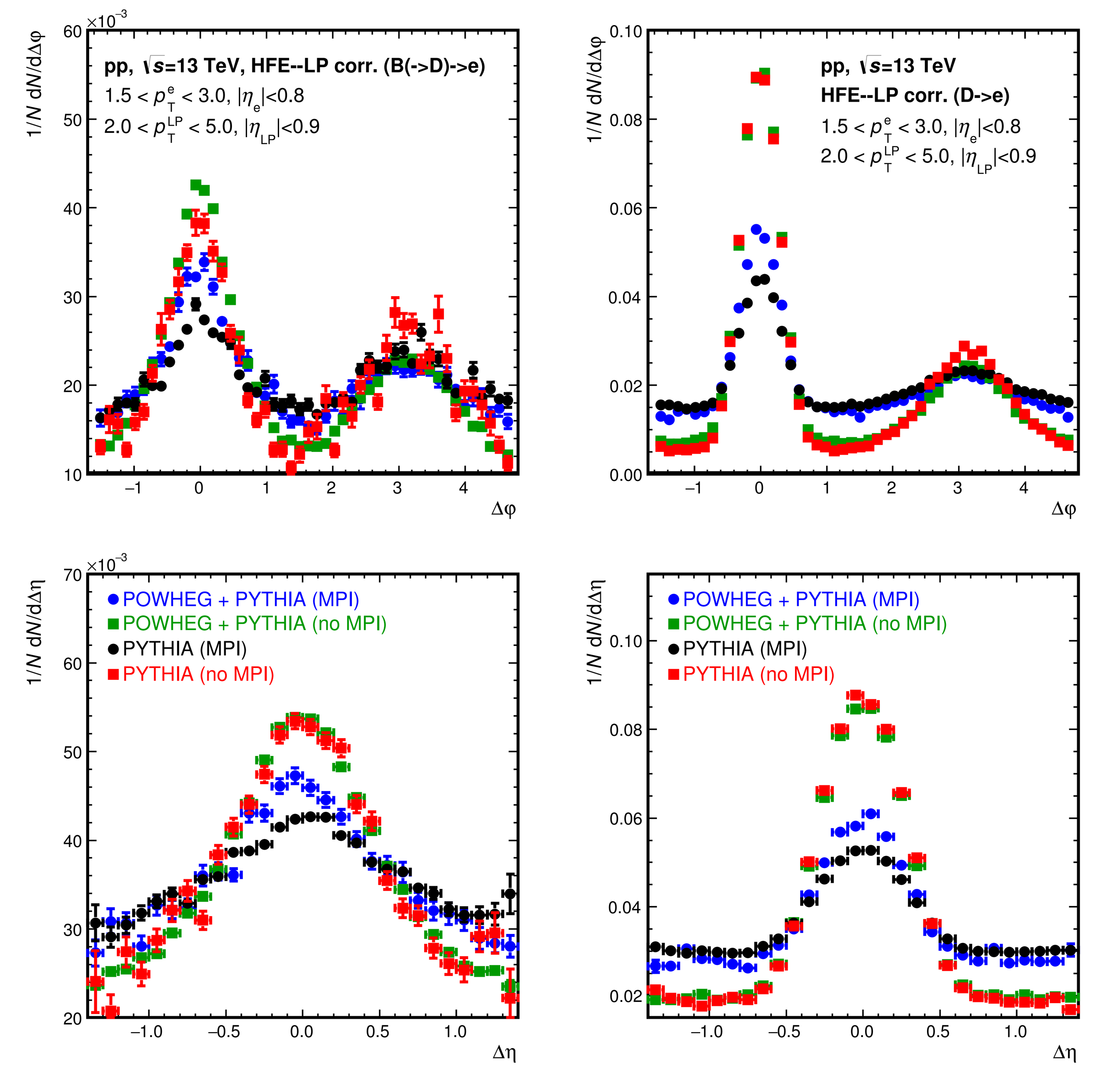
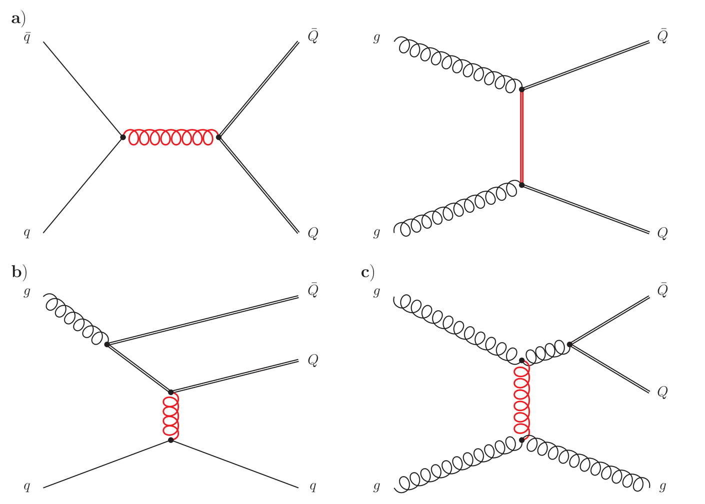


Fig. 3: HFE–LP correlations for beauty (left) and charm (right) contributions.

- The $\Delta\varphi$ and $\Delta\eta$ correlations of charm contributions are much more correlated (Fig. 3) and allow in principle to disentangle both contributions using correlation templates.
- Correlations using MPI are weaker since heavy quarks produced in MPI are not directly correlated to the leading particle.
- The correlations agree between POWHEG and PYTHIA 8 without MPI. However, the predictions differ for the case with MPI since these interactions contribute much more in the case of the minimum bias calculation performed with PYTHIA 8.

HF production mechanisms in PYTHIA 8

- Heavy flavour generation in PYTHIA 8 can be separated into the three processes (Fig. 4): a) pair creation, b) flavour excitation, c) gluon splitting. To prevent double counting, it is required to select the hardest process (hp) in these productions (marked in red).



- The correlations of flavour excitation (Fig. 4b) differ between heavy quarks participating in the hard process (hp) and the one from the initial state gluon splitting that do not participate in the hardest process. These second contributions have been merged together with non-unique cases in the class denoted as "others".

Fig. 4: Exemplary PYTHIA 8 productions mechanisms.

- We studied HFE–hadron (h) and HFE–leading particle (LP) correlations for different p_T cuts on both partners. Both kinds of correlations converge with increasing bias on the momentum of the particle, but HFE–LP correlations show usually more distinct correlation patterns.
- Figure 5 shows that HFE originate dominantly from "NLO" processes like flavour excitation and gluon splitting.
- The correlation patterns in Fig. 6 (flavour combined) emphasize strongest correlations for the flavour excitation which participates in the hardest process. The weakest correlation has been found for the "other" contributions, which involves quarks not participating in the hardest process.

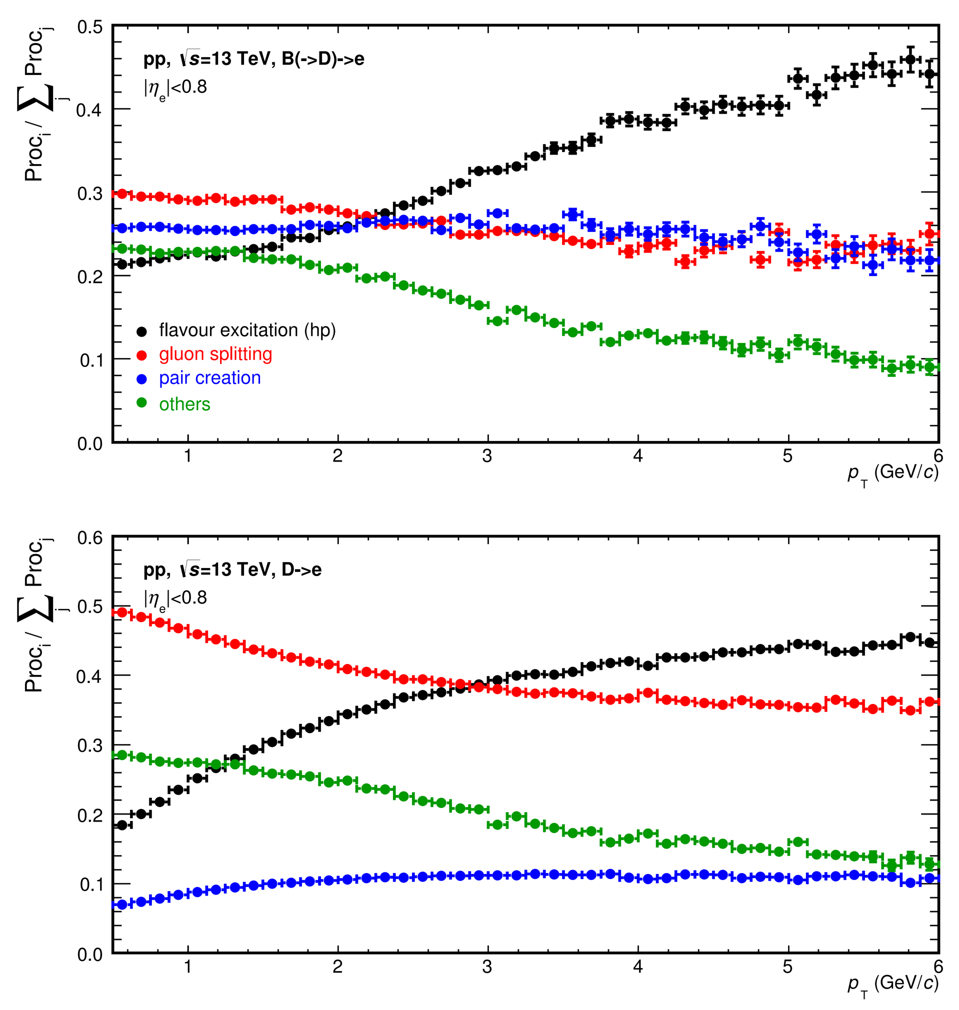


Fig. 5: Fraction of a HF production process to all processes in HFE spectrum.

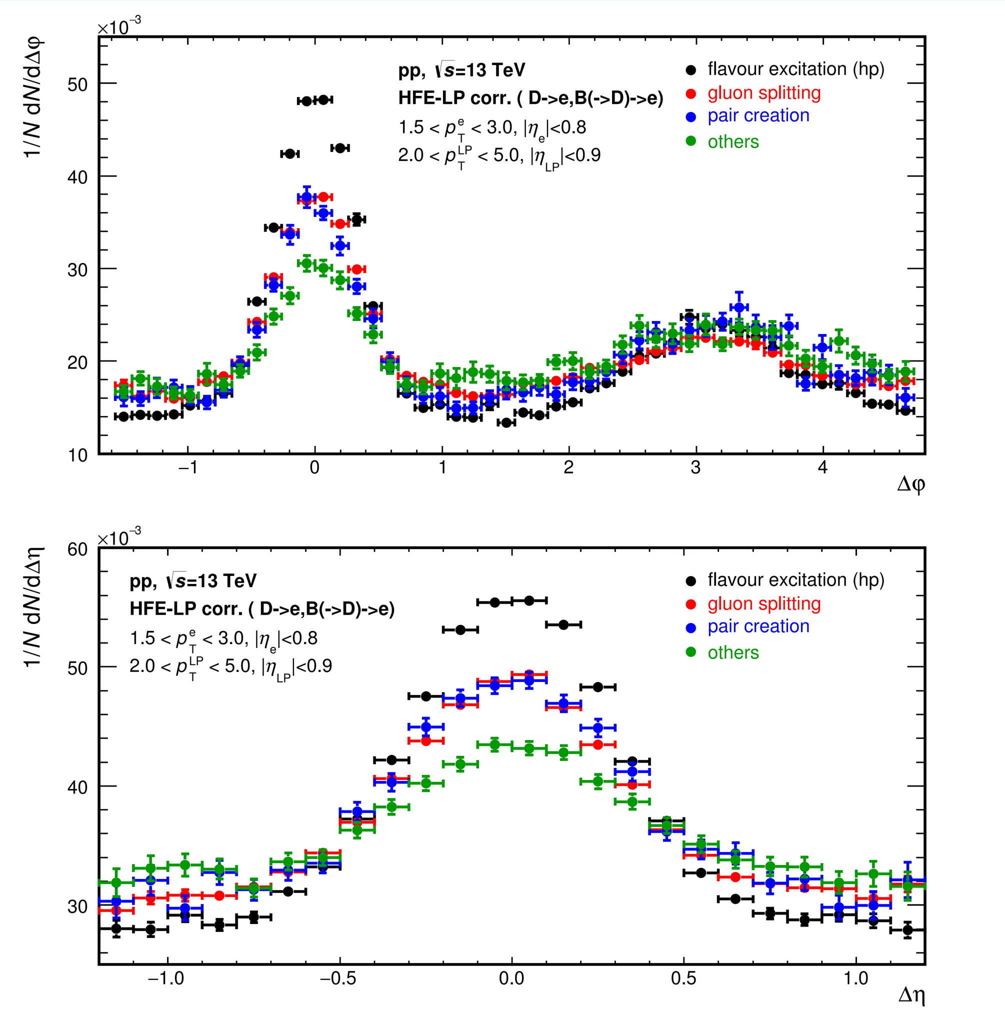


Fig. 6: HFE–LP correlations for different production mechanisms.

Multiplicity dependence in PYTHIA 8

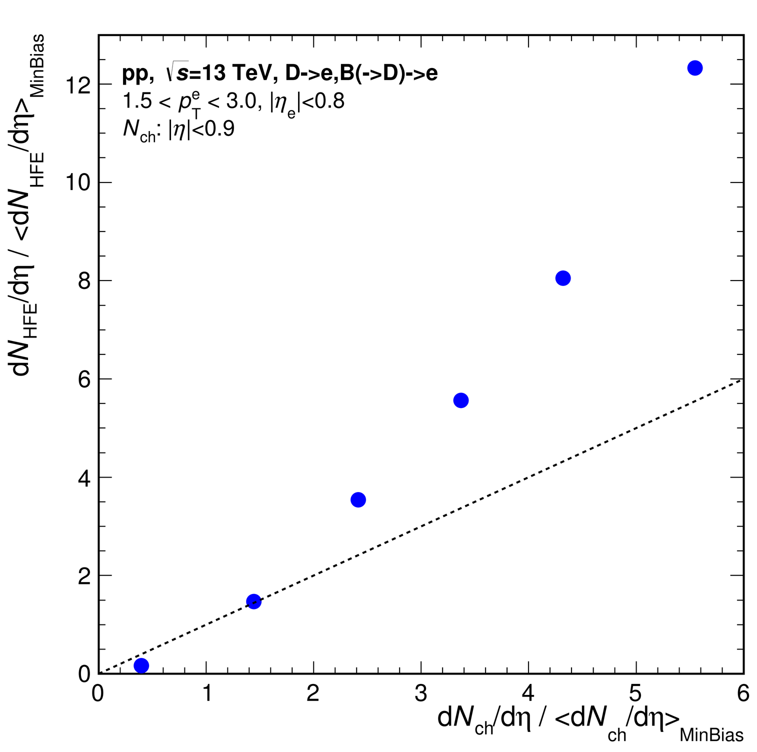


Fig. 7: Self-normalized HFE yield.

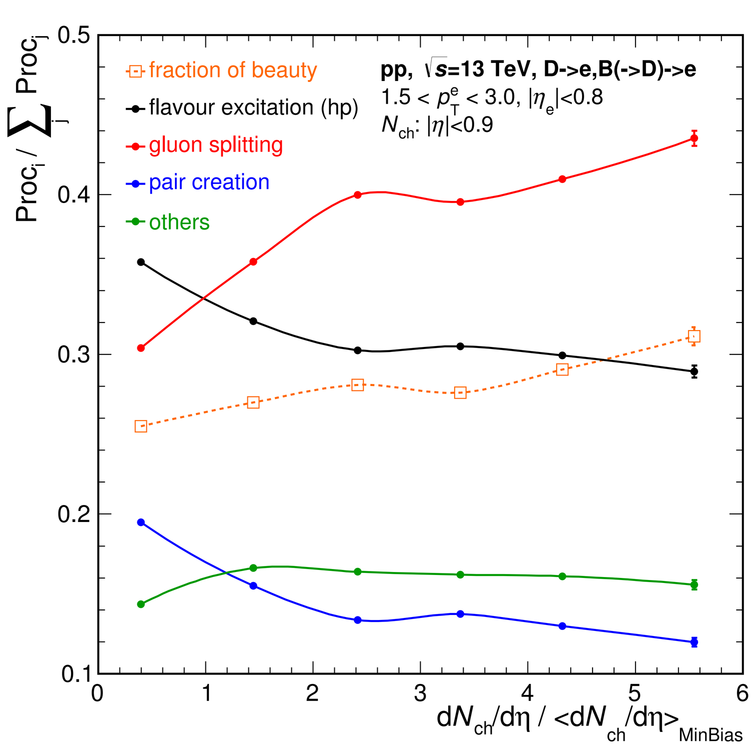


Fig. 8: Fraction of production processes.

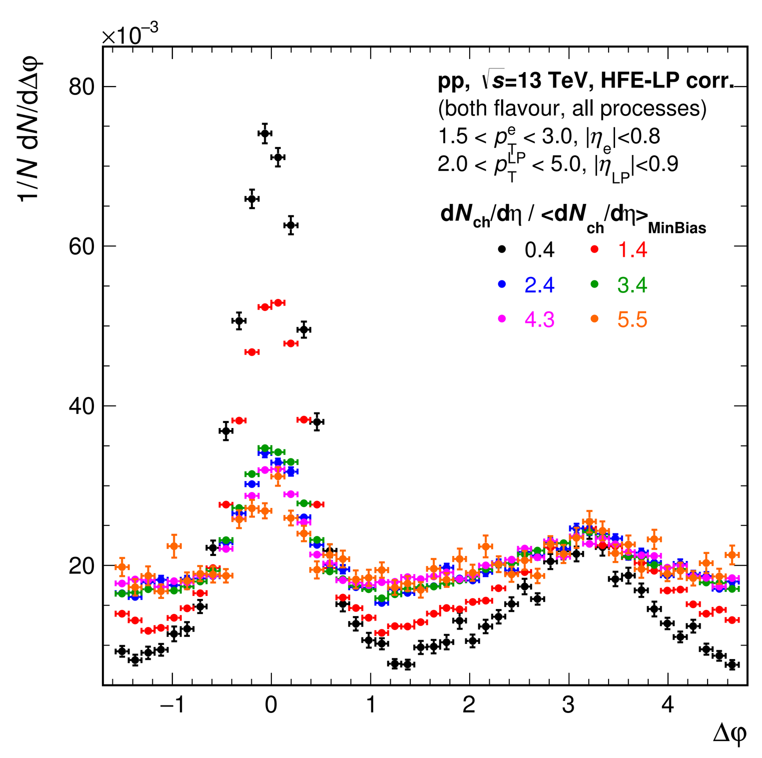


Fig. 9: HFE–LP $\Delta\varphi$ correlations.

- Figure 7 shows stronger than linear increase of the self-normalized yield, which is closely related to the MPI.
- Pair creation and flavour excitation drop with increasing multiplicity (Fig. 8) – resulting together with an increasing number of MPI in weaker correlations in these multiplicity ranges (Fig. 9).

Conclusions

- Exclusive final-state calculations of electrons from heavy-flavour hadron decays using **PYTHIA and POWHEG+PYTHIA without MPI show good agreement between each other**, even in case of correlations, and **good agreement with inclusive predictions provided by FONLL**.
- The **large amount of MPI** weakens the correlations of HFE and have a **non negligible effect in the comparison of minimum bias (PYTHIA 8) and heavy flavour production (POWHEG)**.
- The strength of the **correlations differ for different flavours (c > b), production mechanisms (flavour excitation (hp) > others) and the amount of MPI (no MPI > MPI) / multiplicity (low > high)**.
- **Disentangling these effects via template fits of correlations might be possible**, but is challenged by their interplay.

References:

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