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Measurement of associated production of electrons and muons from heavy-flavour hadron decays in pp collisions with ALICE

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The associated production of electrons and muons from heavy-flavour hadron decays is studied in pp collisions at a centre-of-mass energy $\sqrt{s} = 13.6$ TeV collected by ALICE during the LHC Run 3. The measurement is a powerful tool to probe the correlated charm- and beauty-quark production and to provide new insight on the role of multiple parton interactions. Results from Monte Carlo simulations using PYTHIA8 event generator are discussed and the status of the analysis is presented.

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1. Introduction and physics motivations

The measurement of the production of open heavy-flavour hadrons and their decay particles in high-energy heavy-ion collisions provide unique access to the transport properties of heavy quarks (charm and beauty) in the quark-gluon plasma (QGP), a state of strongly-interacting matter at extreme conditions of temperature and energy density. Charm- and beauty-hadron measurements in pp collisions represent the baseline to quantify hot-medium effects due to the QGP formation, while in p–Pb collisions they allow the investigation of cold nuclear matter effects. These measurements also serve as a crucial test of perturbative quantum chromodynamics (pQCD), and provide insight into heavy-quark production mechanisms and the role of multiple parton interactions (MPI). The latter constitute a possible scenario for the interpretation of QGP-like effects observed in small collision systems.

The associated production of J/ψ was studied by the ALICE Collaboration with data from pp collisions at $\sqrt{s} = 13$ TeV collected during the Run 2 [1]. With Run 3 data, additional studies of the associated production of open and hidden heavy-flavour hadrons can be performed. Among them, the measurement of electron–muon pairs from heavy-flavour hadron decays in pp collisions at $\sqrt{s} = 13.6$ TeV is investigated. This new physics channel becomes accessible thanks to the large data sample collected during the LHC Run 3, due to the continuous readout and higher interaction rate. Such measurement enables the study of different production mechanisms such as single-parton scattering (SPS) where both heavy quarks are produced in the same hard scattering process, and double-parton scattering (DPS) where the two quarks originate from independent parton-parton interactions within the same collision. The DPS is considered as the simplest form of MPI. The two mechanisms exhibit different trends in angular, rapidity and invariant-mass distributions. In particular, contributions from DPS are expected to be more pronounced at large relative rapidities between the electron and the muon [2]. Taking advantage of these kinematic effects, the study of electron–muon pairs is a powerful tool to investigate heavy-quark production mechanisms. Assuming that the parton correlations in the proton are negligible, the contribution of the DPS mechanism [3] can be estimated as

$$\sigma_{\mathrm{DPS}}(ab) = \frac{m}{2} \cdot \frac{\sigma(a) \cdot \sigma(b)}{\sigma_{eff}}, \tag{1}$$

where $m = 1$ ($m = 2$) if the final-state particles a and b are identical (different), and $\sigma(a)$ ($\sigma(b)$) is the a (b) inclusive production cross section. The effective cross section σ_{eff} is related to the transverse overlap between the pairs of interacting partons in the proton. The σ_{eff} factor is expected to be independent of the process and centre-of-mass energy [3].

Moreover, the associated production of electrons and muons from heavy-flavour hadron decays is of particular interest to probe the correlated charm and beauty production. Indeed, in contrast to other dilepton channels, electron–muon pairs are unaffected by contaminations from resonance decays, thermal radiation and Drell-Yan processes.

Open heavy-flavour hadrons are studied in ALICE through the hadronic decay channels and with electrons from semielectronic decays of charm and beauty at midrapidity ($|y| <$

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0.9), and via the semimuonic decay at forward rapidity ($2.5 < y < 4.0$)[1]. A detailed description of the ALICE detector and its performance can be found in Refs. [4, 5] and the major upgrade of the ALICE apparatus that has been successfully carried out for the LHC Run 3 is described in [6]. The analysis presented in these proceedings uses a fraction of the pp sample at $\sqrt{s} = 13.6$ TeV collected in 2023. The analysis is based on i) muons reconstructed in the forward muon spectrometer which covers the pseudorapidity interval $-4.0 < \eta < -2.5$ and ii) electrons are measured at midrapidity in the central barrel (pseudorapidity coverage $|\eta| < 0.9$) by means of the GEM (gas electron multiplier)-Time Projection Chamber [7] and the second generation of the Inner Tracking System [8].

2. Study of the production of heavy-flavour electron–muon pairs in pp collisions at $\sqrt{s} = 13.6$ TeV with PYTHIA8

The results of electron–muon ($\mathrm{e} - \mu$) pairs originating from charm- and beauty-hadron decays are obtained from simulated inelastic pp collisions at $\sqrt{s} = 13.6$ TeV generated with PYTHIA 8.3 [9] with the default Monash 2013 tune [10], activating SoftQCD processes and with MPI switched on. The D and B hadrons are forced to decay in the semileptonic decay channels. The results are presented for muons and electrons in the pseudorapidity interval $-4.0 < \eta < -2.5$ and $|\eta| < 0.9$, respectively and, with a transverse momentum $p_{\mathrm{T}} > 1$ GeV/c for both electrons and muons. The correlated pairs are further tagged according to their heavy-quark production mechanism. The correlated pairs from the D-chain[2] and B-chain[3] are discussed separately.

Figure 1 presents the distributions of the rapidity difference between electrons and muons (Δy) originating from charm (left) and beauty (right) decays. The correlated $\mathrm{e} - \mu$ pairs from charm decays are largely dominated by the gluon splitting process and it is interesting to notice that the correlated $\mathrm{e} - \mu$ pair from the D-chain is suppressed by applying the acceptance and p_{T} selections. Similar trends are reported for the correlated component of $\mathrm{e} - \mu$ pairs from beauty decays. Finally, one observes a significant contribution of uncorrelated $\mathrm{e} - \mu$ pairs from D-hadron decays over the full Δy interval compared to $\mathrm{e} - \mu$ pairs from B-hadron decays.

The distributions of the relative azimuthal angle between electrons and muons originating from charm- and beauty-hadron decays ($\Delta\varphi$) are depicted in Fig. 2 in the left and right panel, respectively. The correlated $\mathrm{e} - \mu$ pairs from charm and beauty decays exhibit a maximum at 180° which indicates that the quark pair is emitted azimuthally back-to-back. An uniform behaviour is observed for the uncorrelated component which is dominated by DPS.

[1] The muon spectrometer covers a negative η range in the ALICE reference frame and consequently a negative y range. The results are chosen to be presented with a positive y notation, due to the symmetry of the collision system.

[2] The D-chain is defined as a D hadron which decays into e (μ) with a light-flavour hadron and the latter further decays into e (μ).

[3] The B-chain, also named $\mathrm{BD_{same}}$, corresponds to a B hadron decaying into e (μ) together with a D hadron and the latter further decays into e (μ).

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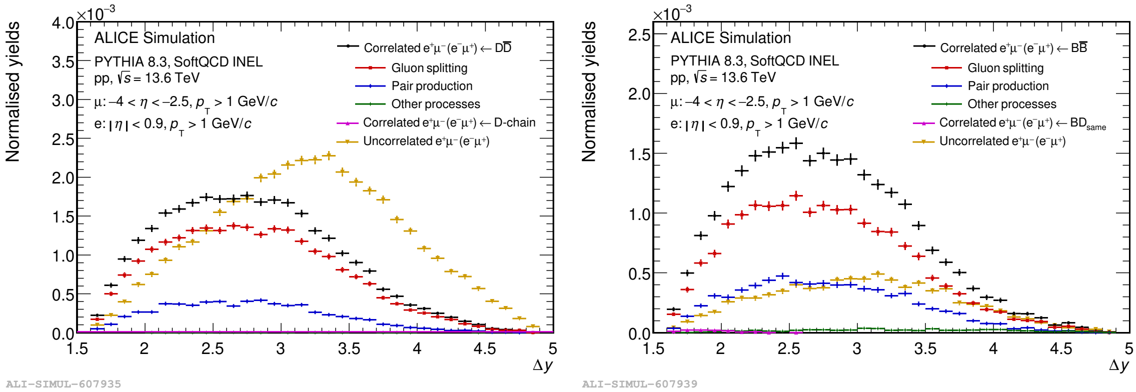

Figure 1: Left: Simulated Δy distribution of $\mathrm{e}-\mu$ pairs from charm-hadron (left) and beauty-hadron (right) decays in pp collisions at $\sqrt{s}$ = 13.6 TeV with the PYTHIA 8 event generator. The η and p_{T} selections applied on electrons and muons are mentioned in the legend. Correlated and uncorrelated $\mathrm{e}-\mu$ pairs are displayed, separately. The contributions due to the different heavy-quark production mechanisms are also shown.

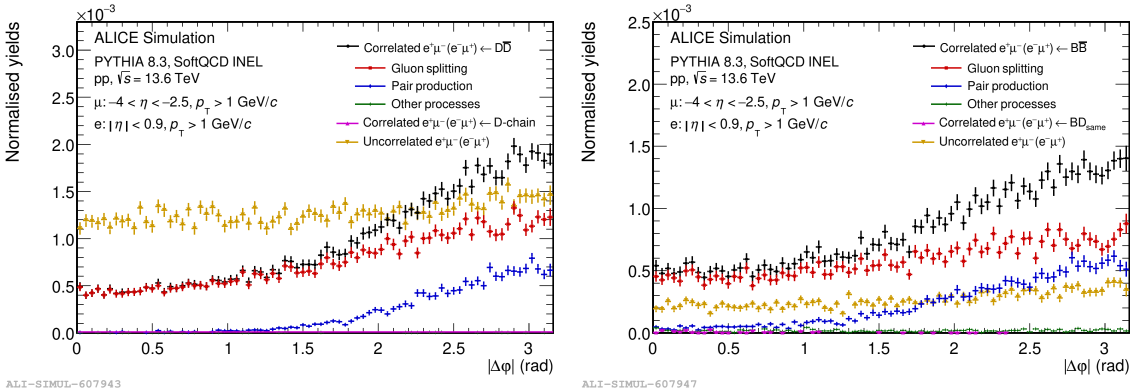

Figure 2: Simulated $\Delta\varphi$ distribution of $\mathrm{e}-\mu$ pairs from charm-hadron (left) and beauty-hadron (right) decays in pp collisions at $\sqrt{s}$ = 13.6 TeV with PYTHIA8 event generator. The η and p_{T} conditions applied on electrons and muons are mentioned in the legend. Correlated and uncorrelated $\mathrm{e}-\mu$ pairs are displayed, separately. The contributions due to the different heavy-quark production mechanisms are also shown.

3. Measurement of electron-muon pairs from heavy-flavour hadron decays in pp collisions at $\sqrt{s}$ = 13.6 TeV

The status of the new study of the associated production of electrons and muons from heavy-flavour hadron decays is reported here, exploiting a subset of the Run 3 minimum-bias pp data at $\sqrt{s}$ = 13.6 TeV (integrated luminosity $\mathcal{L}_{\mathrm{int}}$ = 5.7 pb^{-1}), collected with ALICE. The $\mathrm{e}-\mu$ pairs are measured for electrons and muons with $p_{\mathrm{T}} > 1$ GeV/c in the interval $|\eta| < 0.9$ and $-4.0 < \eta < -2.5$, respectively. Figure 3 presents typical distributions of the rapidity of the $\mathrm{e}-\mu$ pairs (top, left), the rapidity (top, right) and azimuthal angle (bottom, left) difference between the two leptons and the invariant mass (bottom, right). It can be observed that the rapidity distribution of the $\mathrm{e}-\mu$ pairs covers a interval located in

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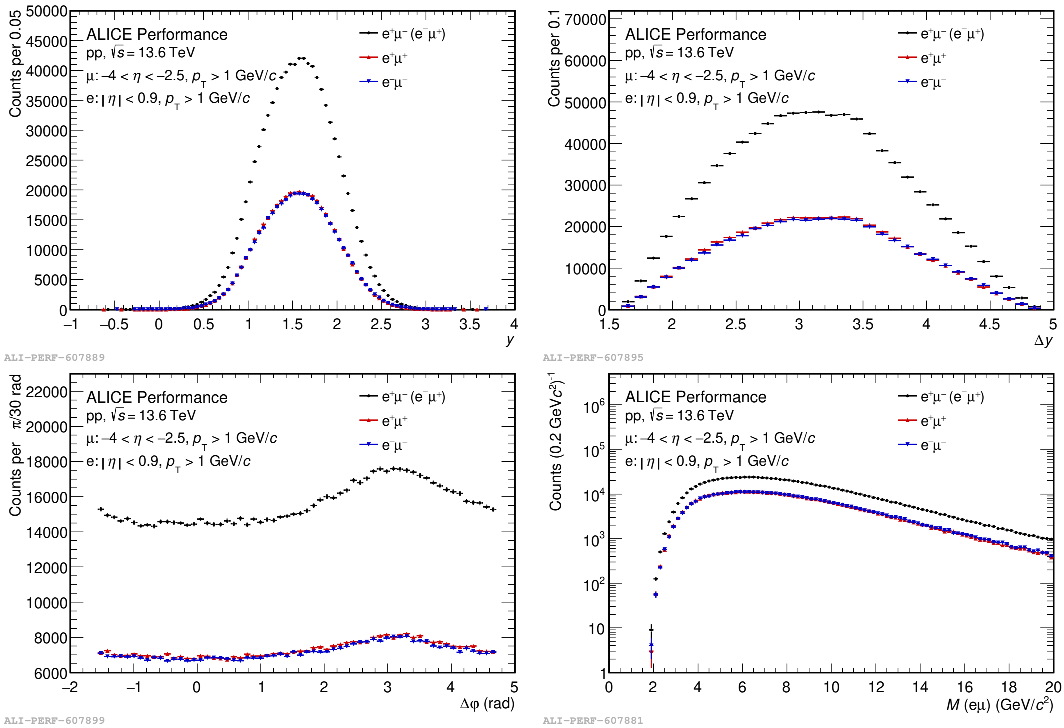

Figure 3: Distributions of the $\mathrm{e}-\mu$ pair rapidity (top, left), rapidity (top, right) and azimuthal angle (bottom, left) difference between electrons and muons and invariant mass (bottom, right) measured in pp collisions at $\sqrt{s}$ = 13.6 TeV. The η and p_{T} conditions applied on electrons and muons are mentioned in the legend. Unlike-sign and like-sign $\mathrm{e}-\mu$ pairs are shown.

an intermediate region between the central barrel and the muon spectrometer. Therefore, this study will complement the existing Run 2 dilepton measurements at midrapidity [11]. It is also interesting to notice that with the measurement of $\mathrm{e}-\mu$ pairs, ALICE provides a unique $|\Delta y|$ reach at the LHC, up to about five units. The $\Delta\varphi$ distribution is peaked at $\Delta\varphi \sim 180°$, as in Fig. 2. As expected, the invariant mass distribution of $\mathrm{e}-\mu$ pairs spreads over several GeV/c^2 without structure, requiring dedicated studies with like-sign and event-mixing techniques for the background estimation as discussed in Ref. [12].

4. Conclusions

In summary, the measurement of the associated production of electrons and muons from heavy-flavour hadron decays becomes feasible exploiting the Run 3 pp data. This is a promising physics channel to extract the correlated charm and beauty production and to discriminate between different production mechanisms.

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