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Study of in-Medium Energy Loss with Heavy-Flavour Correlations in pp and Pb-Pb Collisions with ALICE at the LHC †

Samrangy Sadhu on behalf of the ALICE Collaboration

Variable Energy Cyclotron Centre, Kolkata and Homi Bhaba National Institute, Mumbai, India; samrangy.sadhu@cern.ch; Tel.: +91-7044519040

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Abstract: The azimuthal correlations between heavy-flavour hadrons or heavy-flavour decay electrons with charged particles in Pb-Pb collisions give insight on the modification of charm-jet properties in nucleus-nucleus collisions and the mechanisms through which heavy quarks in-medium energy-loss takes place. Studies in pp collisions, besides constituting the necessary baseline for nucleus-nucleus measurements, are important for testing expectations from pQCD-inspired Monte Carlo generators. In ALICE heavy-flavour hadrons are studied via their fully reconstructed hadronic decays (D mesons and Λ_c baryon), via semileptonic decays of charmed baryons (Λ_c, Ξ_c) and via leptons coming from heavy-flavour hadron decays. In particular in the central barrel, $\eta < |0.8|$, the electrons from heavy-flavour hadron decays are investigated. This proceeding will include the study of azimuthal correlations of D mesons with charged particles in pp collisions and heavy-flavour decay electrons with charged particles in pp and Pb-Pb collisions at different energies available at the LHC. The Experimental results will also be compared with the expectations from POWHEG and PYTHIA event generators.

Keywords: Quark-Gluon Plasma; Heavy quarks; Azimuthal correlations

1. Introduction

ALICE is a dedicated experiment at the LHC to study nuclear matter at extreme conditions of high temperature and high energy density at which quarks are de-confined and gives rise to a new state of matter known as Quark-Gluon Plasma (QGP). Due to their large masses, heavy quarks (charm and beauty), are produced in the early stages of the collision, via hard partonic scattering processes, and they are expected to experience the full evolution of the system propagating through the medium produced in such collisions. Therefore, they are considered to be the ideal probe to study the medium properties.

The angular correlations between heavy-flavour hadrons or heavy-flavour decay electrons and charged particles are sensitive to the charm fragmentation as well as the charm production mechanisms. Thus, this study allows us to characterize the heavy-quark fragmentation process and its possible modification inside the medium. Studies in pp collisions, besides constituting the necessary baseline for nucleus−nucleus measurements, are important for testing expectations from pQCD-inspired Monte Carlo generators.

2. Data Set and Experimental Setup

The ALICE apparatus has excellent capabilities for heavy-flavour measurements. A detailed description of the ALICE detector and its performance can be found in [1]. The sub-detectors used for this analysis are: Inner Tracking System (ITS) for vertex and track reconstruction, Time Projection Chamber (TPC) for track reconstruction and particle identification (PID) via $\mathrm{d}E/\mathrm{d}x$, Time-of-Flight (TOF) for particle identification, V0 (scintillator array) for event triggering, Electromagnetic Calorimeter (EMCal) for high-p_{T} trigger and PID.

The analysis is done with the pp $\sqrt{s}$ = 7 TeV, Pb-Pb $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV from LHC Run1 and pp $\sqrt{s}$ = 13 TeV, p-Pb $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV from LHC Run 2.

3. Analysis Detail

The two particle azimuthal correlation function is defined by the per-trigger associated yield of charged particles i.e.,

$$\frac{1}{N_{\mathrm{trigg}}}\frac{d^2N^{\mathrm{assoc}}}{d\Delta\eta d\Delta\varphi} = B(0,0) \times \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)} \tag{1}$$

where, N_{trigg} is the number of trigger particles. The function $S(\Delta\eta,\Delta\varphi)$ is the differential measure of per- trigger distribution of associated hadrons in the same-event, i.e,

$$S(\Delta\eta,\Delta\varphi) = \frac{1}{N_{\mathrm{trigg}}}\frac{d^2N^{\mathrm{assoc}}_{\mathrm{same}}}{d\Delta\eta d\Delta\varphi} \tag{2}$$

The background distribution function $B(\Delta\eta,\Delta\varphi)$ is defined as:

$$B(\Delta\eta,\Delta\varphi) = \frac{d^2N^{\mathrm{assoc}}_{\mathrm{mixed}}}{d\Delta\eta d\Delta\varphi} \tag{3}$$

The factor B(0,0) in Equation (1) is used to normalize the mixed-event correlation function such that it is unity at $(\Delta\eta,\Delta\varphi) = (0,0)$.

The analysis steps for azimuthal correlations between D mesons and charge particles are:

- The D^0, D^+ and D^{*+} mesons are reconstructed in their hadronic decay channels $\mathrm{D}^0 \to K^-\pi^+$ (BR: 3.88 ± 0.05%), $\mathrm{D}^+ \to K^-\pi^+\pi^+$ (BR: 9.13 ± 0.19%) and $\mathrm{D}^{*+} \to \mathrm{D}^0\pi^+$ (BR: 2.62 ± 0.10%). The Azimuthal correlations are built with associated charged tracks within $|\eta|$ < 1. The D-meson combinatorial background is removed by subtracting the correlation distribution obtained from the sidebands of the D-meson invariant mass distributions [2].
- An event-mixing correction is applied to take care of the detector inhomogeneities and limited acceptance.
- The single and mixed event distributions are corrected for the reconstruction efficiency of the D mesons and the associated tracks.
- The contribution of D mesons coming from beauty-hadron decays is subtracted, using templates of the angular correlations of feed-down D mesons and charged particles obtained from different tunes of the PYTHIA event generator.
- A weighted average of the three D-meson measurements is performed to reduce the statistical uncertainty.
- The azimuthal correlation distributions (normalized with number of triggers) are fitted with two Gaussian functions, to account for the correlation peaks in the near-side ($\Delta\varphi$ = 0) and away-side ($\Delta\varphi = \pi$), and a constant (baseline), allowing us to extract quantitative observables such as the near-side associated yield, near-side peak width and baseline [3].

The analysis steps for azimuthal correlations between heavy-flavour decay electrons and charge particles are following:

- Electrons are identified using TPC $\mathrm{d}E/\mathrm{d}x$ and E/p method, where E is the energy deposited in the calorimeter and p is the track momentum measured by the TPC.

- Non heavy-flavour electrons are identified using invariant mass method where the e^- candidates are combined with all other e^+ with a small opening angle.
- $(\Delta\varphi, \Delta\eta)$ correlation distribution is obtained between inclusive electrons and charged particles.
- Detector effects are corrected using mixed-event technique and correlation distributions are projected on $\Delta\varphi$.
- An efficiency correction is implemented to obtain the $\Delta\varphi$ distribution non-HF contribution.
- The HFe - charged particle distribution is found by subtracting the non-HF $\Delta\varphi$ distribution from the inclusive one followed by a normalization with the number of triggers.

4. Results

An example plot for the azimuthal correlation distribution is shown in Figure 1 for D-mesons with p_T 8–16 GeV/c and charged particle with $p_T > 0.3$ GeV/c. The results of correlation distributions are compared among pp collisions at $\sqrt{s} = 7$ TeV and 13 TeV and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV data and good compatibility within uncertainties is found. This points to the similar charm-jet properties among each collision system. Figure 2 shows the comparison of results in pp collisions at $\sqrt{s} = 7$ TeV and 13 TeV with different Monte-Carlo event generators like PYTHIA6, PYTHIA8 and PYTHIA6+POWHEG [4,5]. From these figures, we can find a good agreement of physical observables with MC generators in the near-side region.

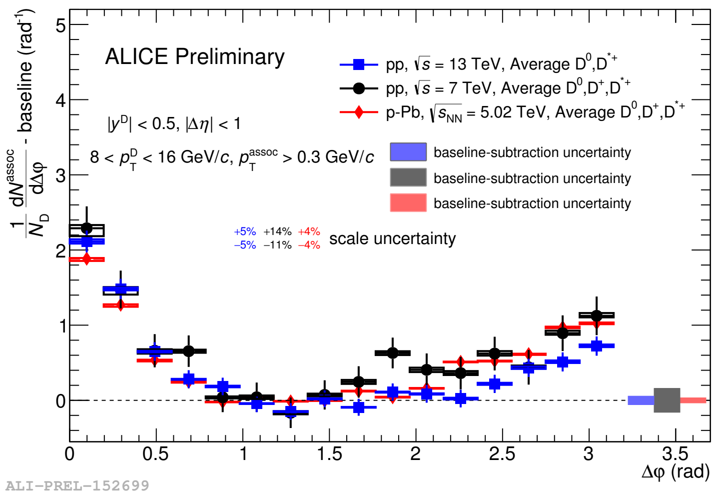
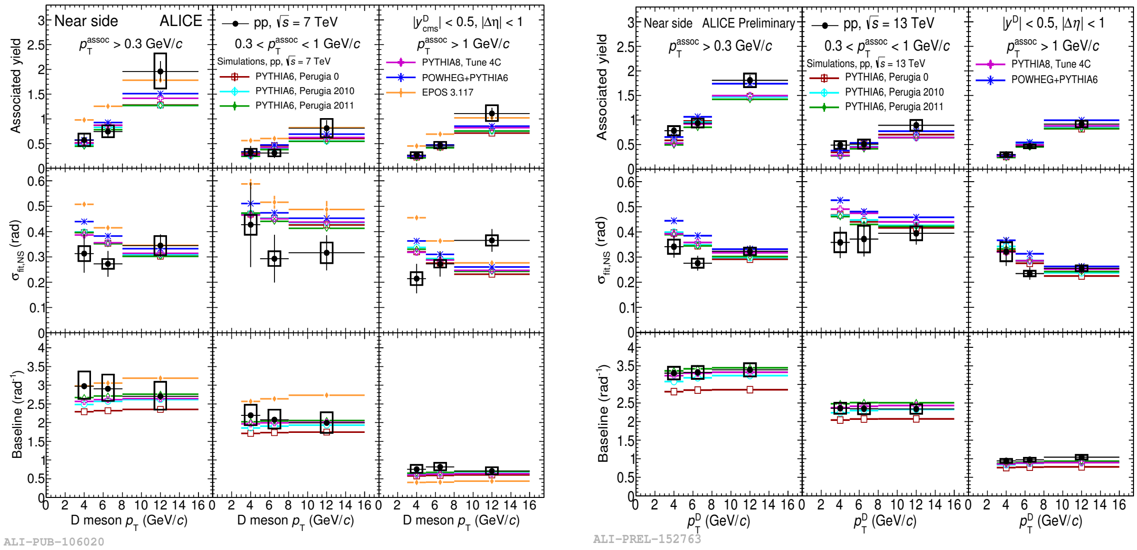


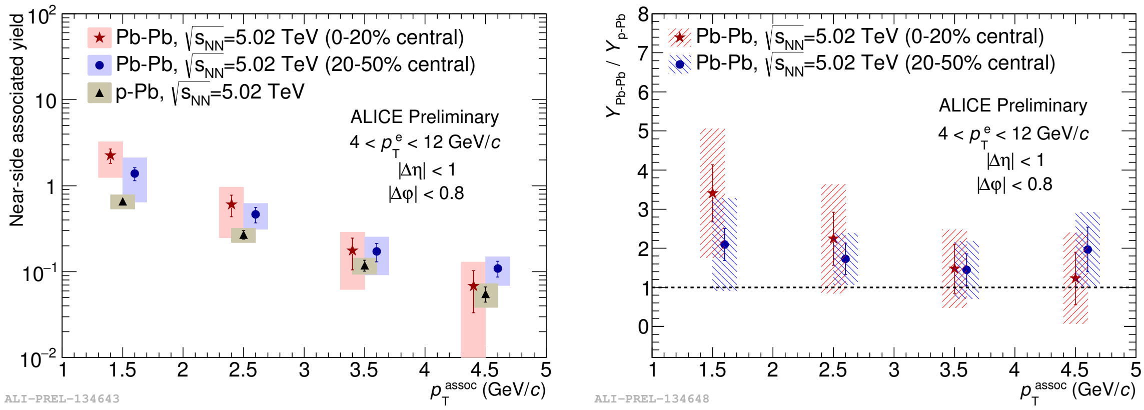
Figure 1. Average azimuthal correlations of D-mesons with charged particles measured in pp collisions at $\sqrt{s} = 13$ TeV compared with those obtained in pp collisions at $\sqrt{s} = 7$ TeV and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV (with subtracted baseline) for the D-meson p_T range $8-16$ GeV/c and charged particle $p_T > 0.3$ GeV/c.

In figure 3, the near-side associated yields from HFe-charged particles azimuthal correlations are shown for Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV with 0-20% and 20-50% centrality classes and results are compared with p-Pb $\sqrt{s_{NN}} = 5.02$ TeV results. From these results, we observe within uncertainties the consistency of Pb-Pb results to that of p-Pb for higher associated p_T, also a hint of near-side yield enhancement of 0-20% most central Pb-Pb collisions with respect to p-Pb collisions is found for the lower associated p_T region.



(**a**) (**b**)

Figure 2. Near-side associated yields, widths and baseline from D-h correlations in pp collisions at (**a**) $\sqrt{s} = 7$ TeV and (**b**) $\sqrt{s} = 13$ TeV compared with PYTHIA6, PYTHIA8, POWHEG+PYTHIA6 and EPOS3 predictions.



(**a**) (**b**)

Figure 3. (**a**) Near-side associated yield for p-Pb and Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. (**b**) Ratio of near-side associated yield of Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV to that of p-Pb collisions with same centre-of-mass energy.

5. Summary and Outlook

The measurements on azimuthal correlations of D mesons and heavy-flavour decay electrons with charged particles in pp, p-Pb and Pb-Pb collisions have been reported. For pp $\sqrt{s} = 13$ TeV, $\sqrt{s} = 7$ TeV and p-Pb at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, the correlation distributions are compatible within uncertainties. The near-side observables show agreement within errors among the different collision system. The results also show good agreement with different MC event generators in the near-side region. For heavy-flavour decay electron-charged particle correlation analysis, there is a hint of an enhancement in the near side for 0-20% most central Pb-Pb collisions. The suppression of away-side correlation peaks gives hint to the in-medium energy loss.

More precise and differential measurements are expected with pp data recorded in 2017 and 2018 and the upcoming Pb-Pb data.

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