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Heavy-flavour elliptic flow measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE

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Abstract

The ALICE Collaboration has measured the production of open heavy-flavour hadrons relative to the reaction plane in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The anisotropy is quantified in terms of the second harmonic, the elliptic flow v_2, in the Fourier expansion of the particle azimuthal distribution. The v_2 measurements are presented for prompt charm mesons, i.e. D^0, D^+, D^{*+}, and heavy-flavour decay electrons at mid-rapidity, as well as for heavy-flavour decay muons at forward rapidity for various centrality intervals. The results are compared with the ones for charged particles and with model calculations of charm and beauty quark transport and energy loss in high-density strongly-interacting matter at high temperature.

Keywords: ALICE; QGP; Ultra-relativistic heavy-ion collisions; Heavy-flavour hadron decay electrons; Elliptic flow

1. Introduction

The main purpose of the ALICE experiment [1] at the LHC is to investigate the properties of the deconfined state of strongly-interacting matter produced in high-energy heavy-ion collisions. Since heavy quarks, i.e. charm and beauty, are produced on a shorter time scale with respect to the hot fireball, they are suited to probe the interaction dynamics inside the medium. A strong modification of the transverse momentum (p_T) distributions of heavy-flavour hadrons was observed in central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [2] via the nuclear modification factor $R_{AA} = (dN_{AA}/dp_T)/(\langle T_{AA}\rangle d\sigma_{pp}/dp_T)$, where dN_{AA}/dp_T is the differential yield in nucleus–nucleus collisions in a given centrality class, $d\sigma_{pp}/dp_T$ is the cross section in pp collisions, and $\langle T_{AA}\rangle$ is the average nuclear overlap function. The large suppression is described at high p_T

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by models including different mechanisms of heavy-quark interactions with the medium. More differential measurements can provide further insights into the relevance of the various mechanisms. The azimuthal distribution of particles with respect to the reaction plane (Ψ_{RP}), defined by the beam axis and the collision impact parameter, can be described by a Fourier series:

$$E\frac{\mathrm{d}^3N}{\mathrm{d}p^3} = \frac{1}{2\pi}\frac{\mathrm{d}^2N}{p_{\mathrm{T}}\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}\left[1+2\sum_{n=1}^{\infty}v_n(p_{\mathrm{T}})\cos n(\varphi-\Psi_{\mathrm{RP}})\right], \tag{1}$$

where E, y, p, φ are the energy, rapidity, momentum and azimuthal angle of the particles, respectively. In case of sufficient re-scattering of the heavy quarks in the medium, the Fourier coefficients v_n for heavy-flavour hadrons reflect the initial spatial anisotropy of the overlap region of the colliding nuclei. In particular the heavy-flavour elliptic flow, v_2, is an observable sensitive to the degree of thermalization of charm and beauty quarks in the medium at low p_{T}, as well as to the path-length dependence of the energy loss of heavy quarks at high p_{T}.

The ALICE Collaboration has measured the v_2 of open heavy-flavour hadrons via their hadronic and semi-leptonic decays in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV. The results presented here are from data recorded during the 2011 LHC runs with an interaction trigger based on the signals from the two scintillators, VZERO-A ($2.8 < \eta < 5.1$) and VZERO-C ($-3.7 < \eta < -1.7$). In total 16 million central (0–10%) and 19 million semi-central (10–50%) Pb–Pb collisions were analyzed.

2. D mesons

The D^0, D^+ and D^{*+} mesons and their charge conjugates are reconstructed in the central barrel of ALICE from their decays into charged hadrons, $\mathrm{D}^0 \to \mathrm{K}^-\pi^+$ (with branching ratio, BR, of 3.88%), $\mathrm{D}^+ \to \mathrm{K}^-\pi^+\pi^+$ (BR = 9.13%), and $\mathrm{D}^{*+} \to \mathrm{D}^0\pi^+$ (BR = 67.7%). Due to their large lifetime ($c\tau = 123$ μm, 312 μm for D^0 and $\mathrm{D}^\pm$ respectively), the D mesons do not decay at the primary vertex. The tracking capabilities of the Inner Tracking System (ITS) and the Time Projection Chamber (TPC) are used to reconstruct the displaced secondary vertices. To further reduce the combinatorial background, the decay $\pi^\pm$ and $\mathrm{K}^\pm$ are identified with the TPC and the Time-Of-Flight (TOF) detectors. An invariant mass analysis is performed to obtain the signal yield. The elliptic flow measured with different methods, i.e. event plane (EP), Q-cumulants and scalar product method [3], is a combination of that of prompt D mesons and of D mesons from beauty hadron decays. The latter contribution is estimated using as input pQCD calculations of B-meson production, together with conservative variations of the unknown R_{AA} and v_2 of D mesons from B decays [4,5].

The prompt-D^0 meson anisotropy was measured in the three centrality classes 0–10%, 10–30% and 30–50%, as reported in Fig. 1. The results show a hint of increasing v_2 from central to semi-peripheral collisions and are comparable in magnitude to that of inclusive charged particles. The averaged v_2 of D^0, D^+ and D^{*+} (shown in the left panel of Fig. 2) indicates a positive v_2 in semi-central (30–50%) Pb–Pb collisions with a significance of 5.7σ for $2 < p_{\mathrm{T}} < 6$ GeV/c.

The v_2 and R_{AA} measurements are compared with models in Fig. 2 [5,6]. The D-meson elliptic flow is best described by calculations that include mechanisms like collisional energy loss in an expanding medium. Charm quark recombination with light quarks from the medium further enhances the D-meson v_2 in some of the models. It is nevertheless challenging for them to describe simultaneously the large suppression of D-meson yield at high p_{T} in central collisions and the significant D-meson v_2 in semi-central collisions, such that the data start to provide constraints for the models.