D Meson Elliptic Flow in Noncentral Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV

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Azimuthally anisotropic distributions of D^0, D^+, and D^{*+} mesons were studied in the central rapidity region ($|y| < 0.8$) in Pb-Pb collisions at a center-of-mass energy $\sqrt{s_{NN}} = 2.76$ TeV per nucleon-nucleon collision, with the ALICE detector at the LHC. The second Fourier coefficient v_2 (commonly denoted elliptic flow) was measured in the centrality class 30%–50% as a function of the D meson transverse momentum p_T, in the range 2–16 GeV/c. The measured v_2 of D mesons is comparable in magnitude to that of light-flavor hadrons. It is positive in the range $2 < p_T < 6$ GeV/c with 5.7σ significance, based on the combination of statistical and systematic uncertainties.

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Heavy-ion collisions at ultrarelativistic energies are aimed at exploring the structure of nuclear matter at extremely high temperatures and energy densities. Under these conditions, according to quantum chromodynamics (QCD) calculations on the lattice, the confinement of quarks and gluons inside hadrons is no longer effective and a phase transition to a quark-gluon plasma (QGP) occurs [1].

The measurement of anisotropy in the azimuthal distribution of particle momenta provides insight into the properties of the QGP medium. Anisotropy in particle momenta originates from the initial anisotropy in the spatial distribution of the nucleons participating in the collision. The anisotropy of produced particles is characterized by the Fourier coefficients $v_n = \langle\cos[n(\varphi - \Psi_n)]\rangle$, where φ is the azimuthal angle of the particle, and Ψ_n is the azimuthal angle of the initial state symmetry plane for the nth harmonic. For noncentral collisions the overlap region of the colliding nuclei has a lenticular shape and the anisotropy is dominated by the second coefficient v_2, commonly denoted elliptic flow [2,3].

The v_2 values measured at RHIC and LHC can be described by the combination of two mechanisms [2,4–12]. The first one, dominant at low ($p_T < 3$ GeV/c) and intermediate (3–6 GeV/c) transverse momentum, is the buildup of a collective expansion through interactions among the medium constituents. Elliptic flow develops mainly in the early stages of this collective expansion, when the spatial anisotropy is large [13–15]. The second mechanism is the path-length dependence of in-medium parton energy loss, due to medium-induced gluon radiation and elastic collisions. This is predicted to give rise to a positive v_2 for hadrons up to large p_T [16,17].

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The measurement of the elliptic flow of charmed hadrons provides further insight into the transport properties of the medium. In contrast to light quarks and gluons that can be produced or annihilated during the entire evolution of the medium, heavy quarks are produced predominantly in initial hard scattering processes and their annihilation rate is expected to be small [18]. Hence, the final state heavy-flavor hadrons at all transverse momenta originate from heavy quarks that experienced all stages of the system evolution. At low p_T, charmed hadron v_2 offers a unique opportunity to test whether also quarks with large mass ($m_c \approx 1.5$ GeV/c^2) participate in the collective expansion dynamics and possibly thermalize in the medium [19,20]. Because of their large mass, charm quarks are expected to have a longer relaxation time, i.e., time scale for approaching equilibrium with the medium, with respect to light quarks [21]. At low and intermediate p_T, the D meson elliptic flow is expected to be sensitive to the heavy-quark hadronization mechanism. In case of substantial interactions with the medium, a significant fraction of low- and intermediate-momentum heavy quarks could hadronize via recombination with other quarks from the bulk of thermalized partons [22,23], thus enhancing the v_2 of D mesons with respect to that of charm quarks [20]. In this context, the measurement of D meson v_2 is also relevant for the interpretation of the results on J/ψ anisotropy [24], because J/ψ's from $c\bar{c}$ (re)combination would inherit the anisotropy of their constituent quarks [25,26]. At high p_T, the D meson v_2 can constrain the path-length dependence of parton energy loss, complementing the measurement of the nuclear modification factor R_{AA} [27], defined as the ratio of the yield in nucleus-nucleus to that observed in pp collisions scaled by the number of binary nucleon-nucleon collisions. A large suppression of the inclusive D meson yield ($R_{AA} \approx 0.25$) is observed in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for $p_T > 5$ GeV/c [28].

Theoretical models of heavy-quark interactions with the medium constituents predict, for semicentral collisions at the LHC, a large v_2 (0.1–0.2) for D mesons at

