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Measurement of R_{AA} and v_2 of electrons from heavy-flavour decays in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE

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Abstract

We present measurements of the nuclear modification factor (R_{AA}) and azimuthal anisotropy (v_2) of heavy-flavour decay electrons by the ALICE Collaboration at central rapidity in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. A strong suppression of heavy-flavour decay electron production at high p_T is observed in central Pb–Pb collisions, while non-zero v_2 is seen at low p_T in semi-central collisions.

1. Introduction

High energy heavy ion collisions generate hot and dense, strongly interacting matter - the quark gluon-plasma (QGP). Measurement of heavy quarks (charm and beauty), arising from hard partonic interactions early in the evolution of the nuclear collision, are of special interest for studying the properties of the QGP. In particular, the energy loss ΔE in the QGP of an energetic parton ("jet quenching") is expected to be influenced by the colour charge of the parton as well as the "dead cone" effect for massive quarks, resulting in the expectation of a hierarchy in energy loss, $\Delta E_g > \Delta E_{light-q} > \Delta E_{heavy-q}$ [1][2][3][4]. Measurement of semi-leptonic decays of D and B hadrons generated in heavy ion collisons give experimental means to study this effect. In addition, the azimuthal anisotropy of heavy quark production observed in non-central heavy-ion collisions is sensitive to the transport properties of the medium, due to the connection between heavy quark diffusion coefficient D, which can be extracted from such measurements, and the ratio of shear viscosity to entropy density (η/s)[5]. The anisotropy is quantified by the second Fourier coefficient v_2 of the particle transverse momentum spectra reconstructed differentially with respect to the reaction plane. In these proceedings we present measurements by ALICE of electrons from semi-leptonic decays of heavy quarks at mid-rapidity in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. We report the p_T dependence of the nuclear modification factor (R_{AA}) in 0-10 % most central collisions, and v_2 of heavy-flavour decay electrons in semi-central collisions (20-40%). We conclude with comparison of the experimental results to several theoretical models.

2. Data analysis

The data were recorded by the ALICE detector [7] during the 2010 and 2011 LHC runs with Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Triggering and event characterizations utilize the VZERO

[1]A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

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detector and Inner Tracking System (ITS). The VZERO detector is composed of two arrays of scintillator tiles covering the full azimuth in the pseudo-rapidity regions $2.8 < \eta < 5.1$ (VZERO-A) and $-3.7 < \eta < -1.7$ (VZERO-C). It contributes to triggering, event centrality measurement, and event plane determination. The Silicon Pixel Detector (SPD) is the innermost part of the ITS and consists of two cylindrical layers of silicon pixel detectors located at radial positions of 3.9 and 7.6 cm from the beam line, covering the pseudo-rapidity ranges $|\eta| < 2.0$ and $|\eta| < 1.4$, respectively. In addition to the centrality triggered event sample (central 0-10% of 17×10^6 events and 20-40% of 8.5×10^6 events), a sample (central 0-10% of 0.7×10^6 events and 20-40% of 1.3×10^6 events) of events triggered by the Electro-Magnetic Calorimeter (EMCal) was used. The EMCal trigger requires an electromagnetic shower above threshold, with the shower defined by a sliding window of 4×4 EMCal cells (corresponding to 0.056×0.056 in $\varphi \times \eta$). The trigger threshold depended online on the integrated signal amplitude in the VZERO detector, which is proportional to the event centrality, and varied from 2 GeV for most peripheral events ($\sigma/\sigma_{\rm geom} \sim 90\%$) to 7 GeV for the most central ($\sim 5\%$) events.

Electron candidates were selected from a set of primary tracks in the Time Projection Chamber (TPC) ($\Delta\phi = 2\pi$, $|\eta| < 0.9$) and in the ITS, with at least one point measured in SPD and with ionization energy loss (dE/dx) of the track within the TPC gas corresponding to the expectation for an electron. Additional hadron rejection utilized time-of-flight measured in the TOF detector ($\Delta\phi = 2\pi$, $|\eta| < 0.9$) and energy deposited in EMCal ($\Delta\phi = 100^\circ$, $|\eta| < 0.7$). Since the shower from an electron is fully contained and accurately measured by the EMCal, the ratio of the energy measured by the EMCal and the momentum measured by the TPC is with high probability close to unity for an electron, but not for a charged hadron.

The measurement of electron yields in the interval $3 - 18$ GeV/c utilized both the TPC and EMCal detectors. The v_2 measurement combined the low-$p_{\rm T}$ electrons ($\gtrsim 1$ GeV/c) identified with TPC and TOF, with the high-$p_{\rm T}$ electrons ($2 - 13$ GeV/c) measured using the TPC and EMCal.

There are three distinct sources of electrons contributing to the population of identified electron candidates: *heavy-flavour electrons* from the semi-leptonic decays of hadrons containing a charm or beauty quark; electrons which originate from leptonic decays of quarkonium (J/ψ and Υ mesons); and *photonic electrons*, originating mainly from photon decays of π^0 and η mesons that convert in detector material. The yield of photonic electrons was measured by pairing electrons with oppositely charged partner tracks and requiring invariant mass of the e^+e^- pair to be close to zero. The contribution from J/ψ decays was estimated using the measured J/ψ production cross section at $\sqrt{s} = 7$ TeV in pp collisions and scaled by an assumed $R_{\rm AA}^{J/\psi} = 0.4$. The heavy-flavour electron yield was then determined by subtracting both the photonic electron yield and feed-down from the J/ψ decays from the inclusive primary electron yield.

The nuclear modification factor for heavy-flavour electrons $R_{\rm AA}^{\rm HF}$ is calculated as:

$$R_{\rm AA}^{\rm HF} = \frac{dN_{\rm AA}^{\rm HF}/dp_{\rm T}}{\langle T_{\rm AA}\rangle d\sigma_{\rm pp}^{\rm HF}/dp_{\rm T}}, \tag{1}$$

where $\langle T_{\rm AA}\rangle$ is the nuclear overlap function for Pb–Pb collisions, $dN_{\rm AA}/dp_{\rm T}$ is the differential yield in Pb–Pb collisions and $d\sigma_{\rm pp}/dp_{\rm T}$ is the differential invariant cross section in pp collisions. In the following, $d\sigma_{\rm pp}/dp_{\rm T}$ was obtained for $p_{\rm T}^{\rm e} < 8$ GeV/c by extrapolating the measured cross-section at $\sqrt{s} = 7$ TeV [8] to 2.76 TeV according to FONLL [9]. For $p_{\rm T}^{\rm e} > 8$ GeV/c, the FONLL calculation for $\sqrt{s} = 2.76$ TeV was used directly.

The heavy-flavour electron $v_{2_e}^{HF}$ was obtained as:

$$v_{2_e}^{HF} = \frac{(1 + R_{NP})v_{2_e} - v_{2_e}^{\gamma}}{R_{NP}}, \tag{2}$$

where v_{2_e} is the inclusive electron v_2 and R_{NP} is the ratio of the number of heavy-flavour decay electrons to photonic electrons (N_e^{HF}/N_e^{γ}) [10]. The inclusive electron v_2 was measured with respect to the event plane, which was determined using the VZERO detectors.

The photonic electron v_2 (v_2^{γ}) was calculated with a Monte Carlo generator that includes the constributions of π^0, η, and direct photons. The measured spectra and $v_2(p_T)$ of $\pi^{\pm}$, π^0, and $K^{\pm}$ were used as input, assuming $v_2^{\pi^{\pm}} = v_2^{\pi^0}$, $v_2^{\eta} = v_2^{K^{\pm}}$. We assume that $v_2 = 0$ for direct photons. At high p_T, $R_{NP} \simeq 4$. TOF and TPC were used to measure v_2 in the interval $1.5 < p_T < 6$ GeV/c, while the TPC and EMCal measure v_2 in the interval $2 < p_T < 13$ GeV/c. The two measurements were combined to obtain the v_2 in $1.5 < p_T < 13$ GeV/c.

3. Results

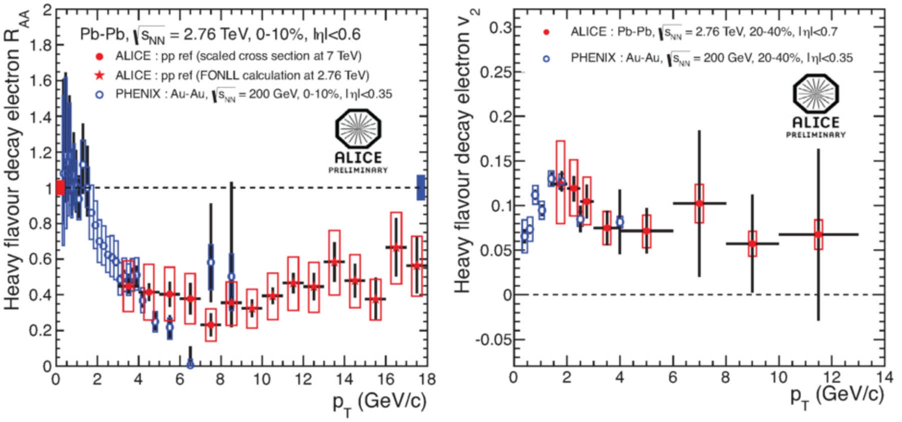

Figure 1: R_{AA} of heavy-flavour decay electrons in 0-10 % central events (left) and azimuthal anisotropy (v_2) in 20-40 % central events (right), in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, compared to measurements at $\sqrt{s_{NN}}$ = 0.2 TeV in Au-Au collisions [11].

The transverse momentum dependence of R_{AA} and v_2 of heavy-flavour decay electrons is shown in Fig 1. We observe a strong suppression of the production ($R_{AA} < 1$) up to 18 GeV/c in central collisions, and non-zero v_2 in $2 < p_T$ (GeV/c) < 3 in semi-central collisions. The suppression in production indicates substantial energy loss of heavy quarks. Since the yield is dominated by beauty decay in the high-p_T region of this measurement, we conclude that beauty quarks experience substantial energy loss. The non-zero v_2 may be determined by the path-length dependence of energy and have a contribution from heavy quark collective flow. Both results are compatible with measurements with Au-Au collisions at $\sqrt{s_{NN}}$ = 0.2 TeV [11].

Figure 2 compares the experimental results with various transport model calculations. The calculations incorporate heavy quark transport with collisional energy loss in an expanding QGP (BAMPS) [2] ; heavy quarks transported with in-medium resonance scattering and coalescence

(Rapp et. al) [3]; and heavy quark transport (Langevin equation) with collisional energy loss (POWLANG) [4].

The BAMPS calculation is in good agreement with the v_2 measurement but does not capture the complete evolution of the R_{AA} at high-p_T. The calculation by Rapp et al. is consistent with the measurement of R_{AA}, but does not reproduce the observed v_2. POWLANG underestimates v_2 and is consistent with the R_{AA} for $p_T < 13$ GeV/c. These comparisons indicate that the combination of R_{AA} and v_2 of heavy-flavour decay electrons provides strong constraints on the theoretical description of heavy-quark transport in the QGP, and that current models are only partially successful in capturing the underlying physics.

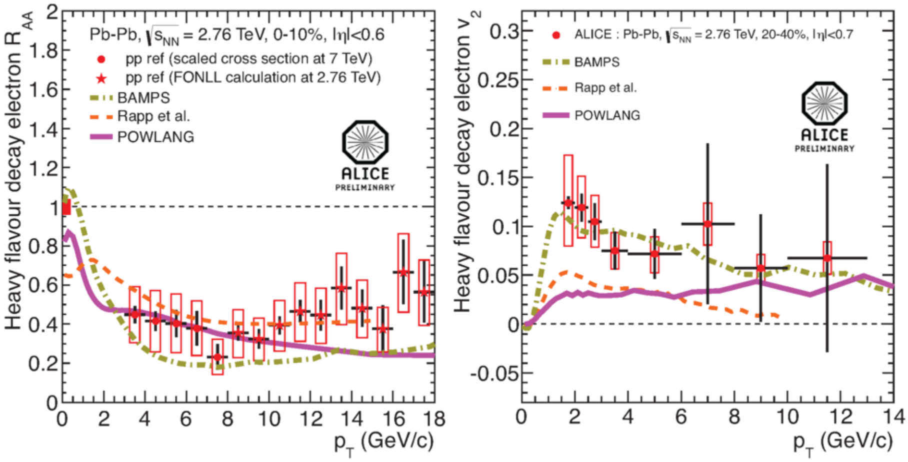

Figure 2: Comparion between measured R_{AA} and v_2 of heavy-flavour decay electrons and theoretical calculations [2] [3] [4]. Calculations are described in the text.

4. Summary

The nuclear modification factor (R_{AA}) and azimuthal anisotropy (v_2) of heavy-flavour decay electrons have been measured in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, by ALICE at the LHC. We observe a strong suppression in the yield of the heavy-flavour decay electrons up to $p_T = 18$ GeV/c in 0-10 % central collision events, and a non-zero v_2 in $2 < p_T$ (GeV/c) < 3 in 20-40 % central collision events. Those results indicate substantial energy loss of heavy quarks in the hot and dense medium formed in Pb–Pb collisions at LHC.

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