D meson elliptic flow in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV measured with ALICE

Grazia Luparello for the ALICE Collaboration

NIKHEF, Utrecht University

E-mail: grazia.luparello@cern.ch

Abstract. These proceedings present the $\rm D^0$, $\rm D^+$ and $\rm D^{*+}$ meson v_2 measured by ALICE in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV with various methods (the standard event plane, the scalar product and the Q-cumulant) and in different centrality classes.

1. Introduction

According to Quantum Chromo Dynamics (QCD) calculations on the lattice, under the conditions of high energy density and temperature reached in high energy nucleus-nucleus collisions a phase transition to a Quark Gluon Plasma (QGP) [1] occurs: in such conditions partons are no longer confined inside hadrons. Heavy-flavour particles are good probes of the properties of the created medium. In particular, the azimuthal anisotropy of heavy-flavour hadron production can provide insight on the degree of thermalization of the heavy quarks in the expanding medium and on the path length dependence of their energy loss [2, 3, 4, 5, 6, 7]. This anisotropy, which is maximum in non-central collisions, originates from an initial geometrical anisotropy with respect to the reaction plane (the plane defined by the beam direction and the impact parameter) that is then converted to a momentum anisotropy by the different pressure gradients in the different directions during the system expansion. The anisotropic pattern can be expressed with a Fourier expansion of the particle momentum azimuthal distribution with respect to the event plane, that is an estimate of the reaction plane. The second order coefficient v_2 is called elliptic flow [8].

In Section 2 of theese proceedings the data sample used and the D meson reconstruction strategy are described, while Section 3 is about the v_2 extraction techniques. Finally in Section 4 the results are summarized.

For this analysis, the following detectors of the ALICE [9] central barrel ($|\eta| < 0.9$) were used: the Inner Traking System (ITS) composed of six layers of high resolution silicon detectors, with the two inner layers consisting of Silicon Pixel Detectors (SPD), a large volume Time Projection Chamber (TPC) and a Time of Flight Detector (TOF). They ensure good capabilities in terms of vertex reconstruction, tracking and particle identification that allow a direct charm v_2 measurement through fully reconstructed D meson hadronic decays.

2. Data sample and D meson reconstruction

The analysis was performed on a data sample of Pb-Pb collisions at a centre-of-mass energy $\sqrt{s_{\rm NN}} = 2.76$ TeV. A minimum-bias trigger was provided by the coincidence of signals in the two VZERO detectors, consisting of two arrays of scintillator counters covering the pseudo-rapidity regions $-3.7 \leq \eta \leq -1.7$ and $2.8 \leq \eta \leq 5.1$. Collisions were classified according to their centrality, defined in terms of percentiles of the hadronic Pb-Pb cross section and determined from the distribution of the signal amplitudes in the VZERO detectors. In addition, an online selection based on the VZERO signal amplitude was used to enhance the number of events with centrality $< 53\%$. Only events with a vertex within ± 10 cm from the centre of the detector along the beam line were considered for the D meson signal analysis. The number of Pb-Pb events analized was 9.5×10^6 in the centrality class 30-50%, 7.1×10^6 in 15-30% and 16×10^6 in 0-7.5%.

Open charm detection in ALICE is based on the invariant-mass analysis of fully reconstructed hadronic-decay topologies. The D meson v_2 was measured in the decay channels $\mathrm{D}^0 \to \mathrm{K}^-\pi^+$, $\mathrm{D}^+ \to \mathrm{K}^-\pi^+\pi^+$ and $\mathrm{D}^{*+} \to \mathrm{D}^0\pi^+$. The separation of a few hundred μm between the primary and secondary vertices, characteristic of D^0 and D^+ decays, was exploited to reduce the combinatorial background. D^{*+} candidates were obtained by combining the D^0 candidates with pion tracks. To further reduce the background, the pion and kaon identification by TPC and TOF detectors was used by applying a selection on the energy deposition $\mathrm{d}E/\mathrm{d}x$ and time of flight. This PID strategy was defined with the aim of preserving most of the signal yield. Further analysis details can be found in [10].

3. v_2 extraction

Different techniques were used to measure the v_2 of the reconstructed D mesons: standard event plane, scalar product and Q-cumulants. Central for all the methods is the evaluation of the flow vector, Q, defined as $Q = (\sum_{i=0}^{N} w_i \sin 2\phi_i, \sum_{i=0}^{N} w_i \cos 2\phi_i)$ where ϕ_i is the angle of the i^{th} track in the ALICE reference frame, w_i are weights applied to tracks depending on their angle in the ALICE reference frame to account for different efficiencies among TPC sectors.

In the standard event plane method (EP) the event plane angle is calculated as $\Psi_n = \arctan(Q_{n,y}, Q_{n,x})/n$. In this case only tracks in the pseudo-rapidity region $0 < \eta < 0.8$ were used to improve the event plane flatness. The invariant mass distribution of the reconstructed D meson candidates was split into in-plane and out-of-plane regions defined as the regions $(0 < \Delta\phi < \frac{\pi}{4}) \bigcup (\frac{3\pi}{4} < \Delta\phi < \pi)$ and $(\frac{\pi}{4} < \Delta\phi < \frac{3\pi}{4})$ respectively, where $\Delta\phi = \phi^{\mathrm{D}} - \Psi_2$. An invariant mass analysis was used to extract the D meson yield in the two regions (N_{in},N_{out}). Knowing N_{in} and N_{out}, v_2 can be directly calculated from Eq. 1, where R is the event plane resolution:

$$v_2 = \frac{\pi}{4}\frac{1}{R}\frac{N_{in} - N_{out}}{N_{in} + N_{out}} \tag{1}$$

The main drawback of the standard event plane method is that the event plane determination is affected by correlations not coming from the genuine correlation of particles with the true reaction plane. This introduces a bias in the flow estimates. Therefore it is useful to compare the results with methods not relying on the event plane determination.

The scalar product method (SP) [11] is based on the evaluation of the quantity $\langle \mathrm{u} \cdot Q^* \rangle$ (where $\mathrm{u} = e^{\imath 2\varphi}$ is the unity vector of the D meson candidate and Q^* is the complex coniugate of the flow vector Q) averaged over all D meson candidates in an event and over all events as in Eq. 2.

$$v_2 = \frac{\langle\langle \mathrm{u} \cdot \frac{Q^*}{M_Q} \rangle\rangle_e}{\sqrt{\langle \frac{Q_A}{M_A} \cdot \frac{Q_B^*}{M_B} \rangle_e}} \tag{2}$$

The vectors Q_A and Q_B are two flow vectors constructed from particles coming from two subevents chosen in different pseudorapidity regions, respectively $0 < \eta < 0.8$ and $-0.8 < \eta < 0$. The D meson candidates are taken from the opposite η region. The vectors Q, Q_A and Q_B are normalized by the number M of particles in each event to reduce the effects of multiplicity fluctuations. Eq. 2 differs from the event plane method, since it uses the magnitude of the flow vector as a weight.

The Q-Cumulants method (QC) [12] is based on the unique relationship between the v_2 coefficient and the so-called Q-cumulants. The mixed correlator between the D meson candidate and reference flow particles (RFP) is calculated. It is defined as $e^{i2(\varphi-\phi)}$, where φ^{D} (ϕ) is the azimuthal angle of the D meson candidate (reference particle) in the ALICE reference frame. The mixed correlator is normalized by the reference flow calculated using RFP. For this analysis reference particles were TPC tracks in the pseudo-rapidity range $|\eta| < 0.8$.

For both the SP and QC method, D mesons candidates were reconstructed in bins of η and p_{T} and the independent particle correlators were calculated for each bin obtaining a distribution of v_2 as a function of the mass of the D meson. The v_2 of the signal (v_2^S) was disentangled from the v_2 of the background (v_2^B) with a simultaneous fit of the invariant mass yield and of the v_2 vs. mass distribution. A Gaussian shape was assumed for the signal peak while the v_2 distribution was fitted with $v_2(x) = S(x)/(S(x) + B(x)) \cdot v_2^S(x) + B(x)/(B(x) + S(x)) \cdot v_2^B(x)$ where x is the mass of the D meson. $v_2^B(x)$ was parametrized with a first order polynomial.

Several sources of systematic uncertainties were considered in the analysis. The main contributions to the total systematic uncertainty come from topological cut selection and from uncertainties on the yield extraction. The analysis was repeated using three different sets of cuts, while the systematic uncertainty on yield extraction was estimated using different background functions in the invariant mass fit and repeating the fit in different mass ranges. For the EP analysis the yields were extracted using also a bin counting method. For the SP and QC methods also the parametrization of the v_2 of the background was varied. The absolute value of the systematic uncertainty from cut variation and yield extraction is ~ 0.05 for D^0 mesons. For the EP method, the variation of the event plane resolution in the centrality range 30-50% introduces a systematic uncertainty of $^{+7}_{-3}$%

The signal sample considered contains also a fraction of D mesons coming from B decays, thus the measured elliptic flow is a combination of prompt and secondary D meson anisotropy. The v_2 of prompt D mesons was obtained assuming that these two contributions have the same elliptic flow and a systematic uncertainty was estimated using as input pQCD calculations of B production, as explained in [10] and including a conservative variation of the unknown R_{AA} (the ratio between the yield measured in AA collisions and the cross section measured in pp

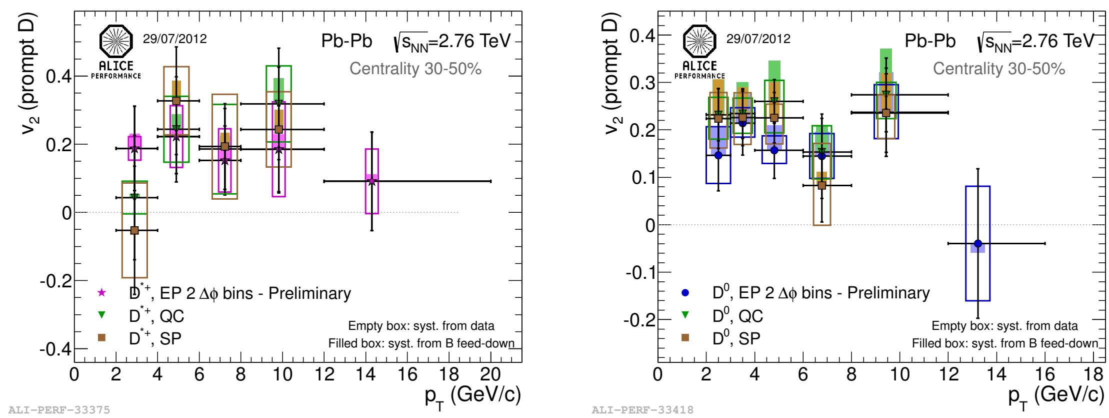

Figure 1. D^{*+} v_2 (left) and D^0 v_2 (right) measured by ALICE in the 30-50% centrality class with EP, SP and QC methods. Empty boxes show systematic uncertainty from data, shaded areas the uncertainty from B feed-down.

collisions, scaled by the overlap nuclear function) and v_2 of D mesons from B decays. This uncertainty extends only towards higher v_2 values and it amounts to up to +23%.

4. Results

The D meson anisotropy was measured in the 30-50% centrality class for D^0 in the range $2 < p_T < 16$ GeV/c, D^+ in $3 < p_T < 8$ GeV/c and D^{*+} in $2 < p_T < 20$ GeV/c. For D^0 and D^{*+} the measurement was carried out using different techniques and the results are in agreement within uncertainties, as shown in Figure 1. The measurement of the v_2 of the D^+ with SP and QC methods is ongoing. Figure 2 (left) shows that the v_2 of D^0, D^+ and D^{*+} is compatible within uncertainties and it is also of similar magnitude as the ALICE measurement of charged hadrons in the same rapidity interval. In Figure 2 (right) the D^0 v_2 measurement in three centrality classes is reported.

In conclusion, the D^0 v_2 is above 0 in the p_T range 2-6 GeV/c with 3σ significance and there is a hint of increasing v_2 from central to semi-peripheral collisions.

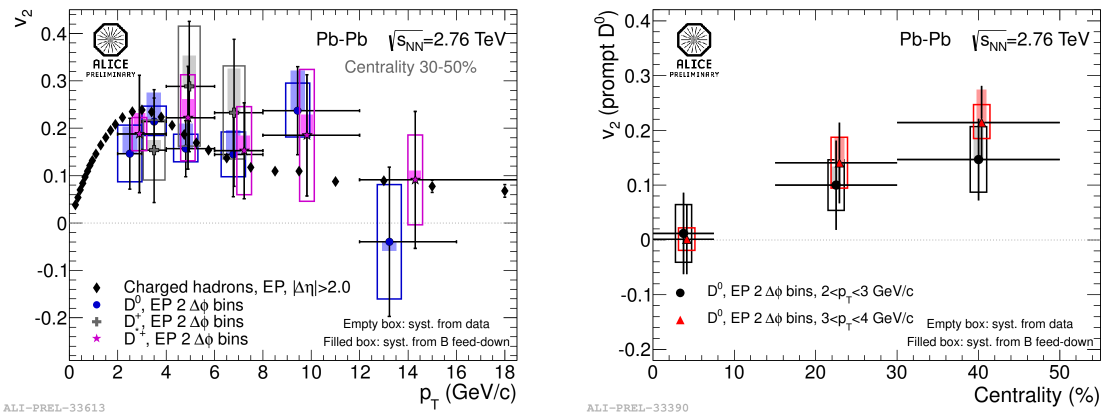

Figure 2. *Left* : D^0, D^+, D^{*+} v_2 measured by ALICE in the 30-50% centrality class with the EP method. Empty boxes show systematic uncertainty from data, shaded areas the uncertainty from B feed-down. Black points show charged hadron v_2[13]. Right: D^0 v_2 mesured by ALICE in the centrality classes 0-7.5%, 15-30% and 30-50%. Empty boxes show systematic uncertainty from data, shaded areas the uncertainty from B feed-down.

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