The Compact Muon Solenoid Experiment

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D meson v_n harmonics in PbPb collisions at 5.02 TeV with CMS

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Abstract

Because of their large mass, heavy quarks are produced primarily at early stages of heavy-ion collisions, and therefore experience the full evolution of the system and carry information about the extent of thermalization of the QGP. Azimuthal anisotropy parameters (v_n) of charm and bottom hadrons provide unique information about the path length dependent interactions between heavy quarks and the medium. To what extent heavy quarks at low p_T flow with the medium is a good measure of the interaction strength. At high p_T , v_2 and v_3 from path length dependent energy loss provide a powerful tool to study heavy quark energy loss mechanisms. With the large PbPb data sample at 5.02 TeV collected by the CMS detector during the 2015 LHC run, azimuthal anisotropy v_2 and v_3 of D0 meson is measured over a wide p_T range and at different centralities. In this talk, new results of D0 meson v_n parameters are presented, and compared to the charged hadron v_n at the same energy and the latest theoretical calculations.

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Prompt D^0 meson v_n harmonics in PbPb collisions at 5.02 TeV

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Abstract

Due to large mass, heavy quarks are produced primarily at early stages of heavy-ion collisions, and therefore experience the full evolution of the system and carry information about the extent of thermalization of the QGP. Azimuthal anisotropy parameters (v_n) of charm and bottom hadrons provide unique information about the path length dependent interactions between heavy quarks and the medium. To what extent heavy quarks at low p_T flow with the medium is a good measure of the interaction strength. At high p_T , v_2 and v_3 from path length dependent energy loss provide a powerful tool to study heavy quark energy loss mechanisms. With the large statistics PbPb samples at 5.02 TeV collected by the CMS detector during the 2015 LHC run, azimuthal anisotropy v_2 and v_3 of D^0 meson is measured over a wide p_T range and at different centralities. In this paper, the most recent results of prompt D^0 meson v_n parameters are presented, and compared to the charged hadron v_n at the same energy and the latest theoretical calculations.

Keywords: quark gluon plasma, heavy flavor, D meson, flow

1. Introduction

The measurement of heavy flavour production is a powerful tool to study the properties of the high-density QCD medium created in heavy-ion collisions as heavy quarks are sensitive to the transport properties of the medium. Compared with gluons and light quarks, heavy quarks are expected to lose less energy due to color charge and dead cone effect [1]. Detailed measurements of both production and azimuthal anisotropy in the final state for charm and bottom hadrons can supply crucial information for understanding the properties of the strongly interacting QCD matter. The Fourier coefficients like v_2 and v_3 of charm and bottom hadrons provide unique information about the interaction between heavy quarks and the medium. At low p_T , whether the heavy flavor quarks completely flow with the medium is an indication of the interaction strength between heavy quarks and the medium. At high p_T , v_2 and v_3 from path length dependent energy loss [2, 3] provide complementary information to nuclear modification (R_{AA}) measurement about the heavy quark energy loss in

the medium. With 2011 PbPb data at 2.76 TeV, CMS has showed good performance in D^0 reconstruction and measured prompt D^0 R_{AA} [4]. Using the large statistics proton-proton and PbPb samples collected at 5.02 TeV during the 2015 LHC run, high precision open charm measurements, including R_{AA} [5] and v_n parameters [6] of prompt D^0 , are performed with the CMS detector [7] in a wide transverse momentum range. In this paper, the most recent results of prompt D^0 meson v_n parameters from CMS [6] are presented, and compared to the charged hadron v_n at the same energy and the latest theoretical calculations. This allows us to set an important milestone in our understanding of the interactions between charm quark and the medium.

2. Analysis

In the analysis, the D^0 candidates are reconstructed from their charged hadronic decay channel $D^0 \rightarrow K^- \pi^+$. A secondary vertex is built for each D^0 candidate. Based on properties of these two-particle secondary vertices, several topological cuts are applied in

Figure 1: Example of the simultaneous fit on mass spectrum (left) and v_2 as function of invariant mass (right).

order to reduce the combinatorial background. One of the cuts is on the impact parameter (b_0) of D^0 candidates to primary vertex, which not only can increase the signal significance, but also can suppress the fraction of non-prompt D^0 (D^0 from B-hadron decay) significantly.

D^0 v_2 and v_3 are measured with “scalar-product” event-plane method (SP method) as expressed in Equation 1.

$$v_n \{SP\} \equiv \frac{\langle Q_n Q_{nA}^* \rangle}{\sqrt{\frac{\langle Q_{nA} Q_{nB}^* \rangle \langle Q_{nA} Q_{nC}^* \rangle}{\langle Q_{nB} Q_{nC}^* \rangle}}}. \quad (1)$$

and Q_n -vectors are defined as

$$Q_n \equiv \sum_{i=1}^M w_i \times e^{in\phi_i}, \quad (2)$$

where M is the number of particles in each event and w_i is a weighting factor. In the analysis, the subscript A , B and C refer to event planes defined using forward calorimeter data (A and B) and tracker data (C). The Q_n vector is computed from D^0 candidates. To avoid the autocorrelation effects, the η gap between D^0 candidates and the correlated event plane A is required to be at least 3 units. To extract v_n of D^0 signal, a simultaneous fit on mass spectrum and v_n as function of invariant mass is performed with Equations 3 and 4.

$$f(m) = Signal(m) + Swapped(m) + Bkg(m) \quad (3)$$

$$v_n^{Sig+Bkg}(m) = \alpha(m)v_n^{sig} + (1 - \alpha(m))v_n^{Bkg}(m) \quad (4)$$

with

$$\alpha(m) = (Signal(m) + Swapped(m))/f(m) \quad (5)$$

$v_n^{Bkg}(m)$ is the v_n of background D^0 candidates and is modeled as a linear function of invariant mass. $\alpha(m)$ is the D^0 signal fraction as a function of invariant mass. The $k-\pi$ swapped component is included in signal fraction because these candidates are from real D^0 and should have same v_n value with real D^0 signal. Figure 1 shows an example of the simultaneous fit on mass spectrum and v_2 as function of invariant mass.

The D^0 signal in data is a mixture of prompt and non-prompt D^0 , thus the v_n^{sig} above is a combination of v_n of prompt and non-prompt D^0 . To evaluate the systematic uncertainties from non-prompt D^0 , the prompt D^0 fractions (f_{prompt}) are evaluated with a data-driven method, which performs a fit on the distribution of impact parameter (b_0) of D^0 candidates to primary vertex. To suppress the fraction of non-prompt D^0 , an upper cut on b_0 is applied in the analysis as mentioned above. The prompt D^0 fractions are found to be around 80-95% after all analysis cuts. With some calculation, v_n^{prompt} can be expressed as:

$$v_n^{prompt} = v_{n,1}^{sig} + \frac{1 - f_{prompt,1}}{f_{prompt,1} - f_{prompt,2}} (v_{n,1}^{sig} - v_{n,2}^{sig}) \quad (6)$$

where subscript 1 and 2 refer to with and without upper cut on b_0 , respectively. The v_n of D^0 from data with upper cut on b_0 , $v_{n,1}^{sig}$, is kept as central values in this analysis while the second term, $\frac{1 - f_{prompt,1}}{f_{prompt,1} - f_{prompt,2}} (v_{n,1}^{sig} - v_{n,2}^{sig})$, is assigned as systematic uncertainties due to non-prompt D^0 .

Figure 2: Prompt D^0 v_2 for centrality 0-10% (left), 10-30% (middle) and 30-50% (right). Charged particle v_2 [8] and theoretical calculations [9–12] are also plotted for comparison.

Figure 3: Prompt D^0 v_3 for centrality 0-10% (left), 10-30% (middle) and 30-50% (right). Charged particle v_3 [8] and theoretical calculations [9] are also plotted for comparison.

3. Results

Azimuthal anisotropy v_2 and v_3 of prompt D^0 are measured as function of p_T for centrality classes 0-10%, 10-30% and 30-50% with uncertainties from non-prompt D^0 evaluated in a data-driven method. It is the first measurement on v_3 of prompt D^0 .

Figure 2 shows prompt D^0 v_2 for centrality classes 0-10%, 10-30% and 30-50%. Charged particle (dominated by light flavor hadrons) v_2 [8] and theoretical calculations [9–12] are plotted for comparison. In the most central collisions (centrality 0-10%), prompt D^0 v_2 is found to be consistent with charged particle v_2 within uncertainties in the studied p_T range. In centrality classes 10-30% and 30-50%, prompt D^0 v_2 is found to

be positive both in low p_T and high p_T ranges, which indicates the charm quarks take part in the collective motion of the system at low p_T and the path length dependent energy loss at high p_T . Besides, D^0 v_2 first increases with p_T in the p_T range around 1 GeV/c to 4 GeV/c and then decreases as p_T increases in the higher p_T range, which is the similar trend with charged particle v_2 . Prompt D^0 v_2 is found to be smaller than charged particle v_2 in the p_T range around 1 GeV/c to 6 GeV/c while becomes consistent with charged particle v_2 in higher p_T range. Furthermore, based on results in centrality classes 10-30% and 30-50%, prompt D^0 v_2 does not have such a strong centrality dependence as it in the case of charged particle v_2 . From the comparison between prompt D^0 v_2 and theoretical

calculations, calculations from LBT model [9] are generally consistent with the measured results within uncertainties in the studied p_T range for the 3 centrality classes. The viscous hydrodynamic calculations from L. Pang [12] are consistent with measured results in p_T range around 1 GeV/c to 3 GeV/c. Calculations from TAMU model [11] and CUJET3 model [10] can qualitatively describe the shapes of measured prompt D^0 v_2 while the calculated values are lower or higher than measured results in some centrality classes.

Figure 3 shows prompt D^0 v_3 for centrality 0-10%, 10-30% and 30-50%. Charged particle v_3 [8] and theoretical calculations [9] are plotted for comparison. Prompt D^0 v_3 is found to be positive for p_T from around 2 to 8 GeV/c for while becomes consistent with 0 within uncertainties in higher p_T range. The p_T dependence of D^0 v_3 is similar to that of D^0 v_2 and charged particle v_3 , increasing with p_T in the p_T range around 1 GeV/c to 4 GeV/c and then decreasing as p_T increases in the higher p_T range. Compared with charged particle v_3 , prompt D^0 v_3 is lower in p_T range around 1 GeV/c to 6 GeV/c and becomes consistent with charged particle v_3 in higher p_T range, which is the same as trend showed in comparison of v_2 . The v_3 exhibits similar magnitudes in 0-10%, 10-30% and 30-50% centrality bins, which is the consistent with the centrality dependence of charged particle v_3 . The calculations from LBT model [9] are generally consistent with measured prompt D^0 v_3 results within uncertainties.

4. Conclusions

In summary, azimuthal anisotropy v_2 and v_3 of prompt D^0 is measured with scalar-product method in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with CMS, which is the first measurement on v_3 of D^0 . To extract v_2 and v_3 of prompt D^0 , the systematic uncertainties from non-prompt D^0 are studied in a data driven method. Prompt D^0 v_2 is found to be positive in studied p_T range 1 to 40 GeV/c, and prompt D^0 v_3 is found to be positive in p_T range around 1 to 8 GeV/c for the first time. In non-central collisions, the measured prompt D^0 v_n ($n = 2, 3$) is found to be lower than v_n of charged particles in p_T range 1 to 6 GeV/c and consistent with v_n of charged particles in higher p_T range. The results provide important information towards understanding interactions between heavy quarks and the medium, and put strong constraints on theoretical studies.

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