Investigation of in-medium effects of charmonia using azimuthal anisotropy and jet fragmentation function in PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with the CMS experiment

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Abstract. Quarkonia have been long proposed as the golden probes to study quark-gluon plasma (QGP) in heavy-ion collisions. In this presentation, we present the second- and third-order Fourier coefficients, v_2 and v_3, for prompt and nonprompt J/ψ mesons in PbPb collisions as functions transverse momentum (p_{T}) and PbPb collision centrality. Also, we report the first measurements of v_2 and v_3 for the prompt ψ(2S) mesons in PbPb collisions. The results provide v_2 and v_3 values over the wide studied kinematics regions of transverse momentum and collision centrality.

1 Introduction

Quarkonia (bound states of a heavy quark and its antiquark such as J/ψ, $\psi(2S)$, $\Upsilon(1S, 2S, 3S)$, etc.) are useful probes to study the properties of the quark-gluon plasma (QGP) in heavy ion collisions [1, 2]. Since heavy quarks are produced via hard parton scattering at early stages of the collisions, they experience the whole space-time evolution of the medium. Azimuthal correlation of these particles can be characterized by the Fourier coefficients (v_n) of the azimuthal distribution. In particular, the second (v_2) and the third (v_3) order components are sensitive to the initial collision geometry and event-by-event fluctuations, respectively. The azimuthal correlation of quarkonium states are useful in particular to study the quarkonium dynamics and its collectivity inside the QGP [3]. In addition, the path-length dependent suppression of quarkonium states could be captured by measurements of quarkonium v_2 values [4].

This conference proceeding reports the measurement of the v_2 and v_3 values for prompt and nonprompt (decayed from b-hadrons) J/ψ mesons, as well as for the prompt ψ(2S) mesons using the scalar product method [5]. The data set used in this analysis was collected with the CMS detector in PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, corresponding to an integrated luminosity of 1.6 nb^{-1}.

2 Analysis procedure

The charmonia are identified using their dimuon decay channel. The separation of the prompt and the nonprompt charmonia relies on the displacement of a secondary $\mu^+\mu^-$ vertex relative to the primary collision vertex. The pseudo-proper decay length is defined as $\ell_{\mathrm{J}/\psi} = L_{xyz}\, m_{\mathrm{J}/\psi}\, c/|p_{\mu\mu}|$, where L_{xyz} is the distance between the primary and dimuon vertices,

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$m_{J/\psi}$ is the world average value of the J/ψ meson mass, and $p_{\mu\mu}$ is the dimuon momentum. To extract prompt and nonprompt J/ψ meson yields, the invariant mass spectrum of $\mu^+\mu^-$ pairs and their $\ell_{J/\psi}$ distribution are fitted using a two-dimensional (2D) extended unbinned maximum likelihood fit. For ψ(2S) mesons, the nonprompt component is reduced by placing tight constraints on the $\ell_{J/\psi}$ distributions. The detailed procedure of the fitting can be found in [6].

The v_n (n = 2 and 3) values of J/ψ and ψ(2S) candidates are determined using the scalar product method [5]. The event plane angle for the second- and third-order harmonics are defined using Q-vectors in the complex plane $Q_n = \sum_{k=1}^{M} \omega_k e^{in\phi_k}$, and are obtained using the tracker or hardron forward (HF) calorimeters. Here, k runs over the particles sampled by the subdetector; M is the multiplicity of particles in the tracker or the number of towers for HF; ϕ is the azimuthal angle of the particle or the tower; ω is the weighting factor given by the p_T of a particle for the tracker or the transverse energy deposited in an HF tower. In this analysis, three event plane Q-vectors are calculated using the tracker at the mid-pseudorapidity ($|\eta| <$ 0.75) and the two HF calorimeters covering the forward ($3 < \eta < 5$, HF+) and backward ($-5 < \eta < -3$, HF−) regions. The v_n coefficients for J/ψ or ψ(2S) mesons are obtained as:

$$v_n\,\{\mathrm{SP}\} \equiv \frac{\left\langle Q_n^{J/\psi,\psi(2S)} Q_{nA}^{*} \right\rangle}{\sqrt{\frac{\langle Q_{nA} Q_{nB}^{*}\rangle \langle Q_{nA} Q_{nC}^{*}\rangle}{\langle Q_{nB} Q_{nC}^{*}\rangle}}}. \tag{1}$$

The subscripts A and B refer to either HF+ or HF−, depending on the rapidity of the J/ψ or ψ(2S) candidate. To avoid autocorrelations, the η gap between the J/ψ or ψ(2S) candidate and the detector used for event plane determination is required to be at least three units of rapidity [5, 7, 8]. For this purpose, HF+ is selected for A (B) when J/ψ and ψ(2S) candidates are produced at negative (positive) rapidity. The $\langle\rangle$ indicates the real component of the average Q-vector product of all the candidates in a given invariant mass bin. The subscript C denotes the event plane taken from the tracker. The denominator in Eq.(1) is the correction factor to remove finite resolution effect of the detectors.

To extract the prompt and nonprompt J/ψ meson v_n coefficients, the J/ψ candidates are sampled into fine v_n intervals. Then, a simultaneous fit of the invariant mass and the $\ell_{J/\psi}$ distributions, as described above, is performed in each interval.

A different method is used to extract the prompt ψ(2S) meson v_n values. The v_n values are extracted by a simultaneous fit on the invariant mass and v_n distribution of ψ(2S) mesons using a binned χ^2 fit method. The v_n distribution is fitted to the following formula:

$$v_n{}^{\mathrm{Sig+Bkg}}(m_{\mathrm{inv}}) = \alpha(m_{\mathrm{inv}}) v_n{}^{\psi(2S)} + [1 - \alpha(m_{\mathrm{inv}})] v_n{}^{\mathrm{Bkg}}(m_{\mathrm{inv}}), \tag{2}$$

3 Results

The measured v_2 and v_3 values for prompt and nonprompt J/ψ mesons in PbPb collisions are shown in Fig.1 as functions of p_T and $\langle N_{\mathrm{part}}\rangle$, which is the average number of participating nucleons [9]. Results for the prompt J/ψ mesons show a flat v_2 for $p_T > 9$ GeV/c, while no clear dependence on p_T is found for nonprompt J/ψ mesons. Previous studies from CMS found the J/ψ being produced in large surrounding jet-activity, which suggested the importance of incorporating jet quenching in describin J/ψ suppression in PbPb collisions at high-p_T [10]. The sizable v_2 of prompt J/ψ mesons at high-p_T in Fig.1 implies the large contribution from path length dependent jet energy loss into the final measured v_2. The v_2 values for nonprompt J/ψ mesons are found to be smaller than those for prompt J/ψ mesons in the studied kinematic region. This finding indiciates different medium effects for charm and bottom quarks induced by the interaction with the QGP.

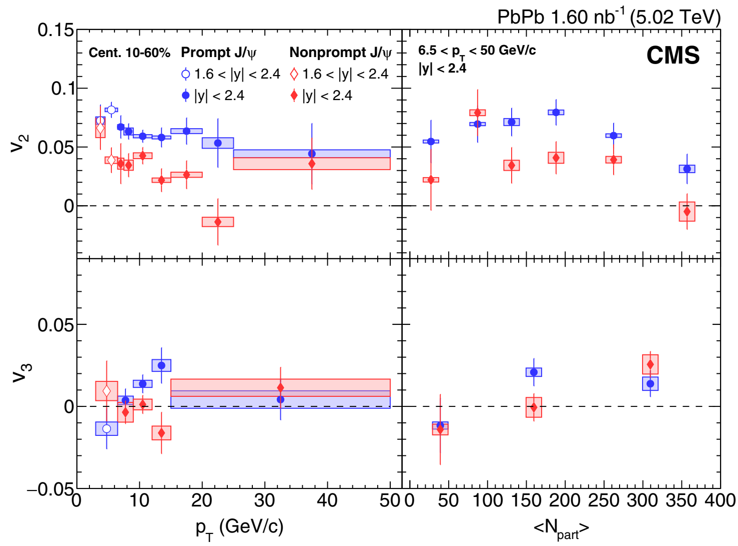

Figure 1. The v_2 (upper) and v_3 (lower) values as functions of $p_{\rm T}$ (left) and $\langle N_{\rm part} \rangle$ (right) for prompt and nonprompt J/ψ mesons. The results for $3 < p_{\rm T} < 6.5$ and $6.5 < p_{\rm T} < 50$ GeV/c are studied in the rapidity range of $1.6 < |y| < 2.4$ and $|y| < 2.4$, respectively (left panel). The results for $p_{\rm T}$ bins for the right panel is 6.5–50 GeV/c and rapidity of $|y| < 2.4$. The vertical bars denote the statistical uncertainties, and the rectangular bands show the systematic uncertainties.

Figure 2 shows the first v_n measurements of the azimuthal anisotropy for prompt ψ(2S) mesons in heavy ion collisions together with the results for prompt J/ψ mesons. The v_2 values are found to be slightly larger for the prompt ψ(2S) than for the prompt J/ψ mesons, especially at higher $p_{\rm T}$ and in peripheral PbPb collisions, although the large uncertainties prevent from making a firm conclusion, with p-values of at best 10%. The v_3 values are found to be consistent with zero in the studied kinematic range.

4 Summary

The second-order (v_2) and third-order (v_3) Fourier coefficients of the azimuthal distributions for prompt and nonprompt J/ψ mesons and prompt ψ(2S) mesons are measured in PbPb collisions as functions of transverse momentum ($p_{\rm T}$) and $\langle N_{\rm part} \rangle$. The v_2 values for prompt and nonprompt J/ψ mesons both indicate a decreasing trend from mid-central towards central collision events. On the other hand, the v_2 is found to be flat for $p_{\rm T} > 9$ GeV/c for prompt J/ψ mesons, while the dependence on $p_{\rm T}$ is found to be weak for nonprompt J/ψ mesons. The prompt J/ψ meson v_2 values are found to be larger than that of nonprompt J/ψ mesons throughout the studied kinematic region, suggesting different in-medium effects for charm and bottom quarks. The observation of sizable and flattened v_2 values at high $p_{\rm T}$ for prompt J/ψ mesons provides a hint of the contribution of jet quenching to prompt J/ψ meson suppression. The J/ψ v_3 values are reported for the first time separately for prompt and nonprompt components, which are found to be consistent with zero in the measured $p_{\rm T}$ and centrality intervals. The v_2 and v_3 values are also measured for prompt ψ(2S) mesons for the first time

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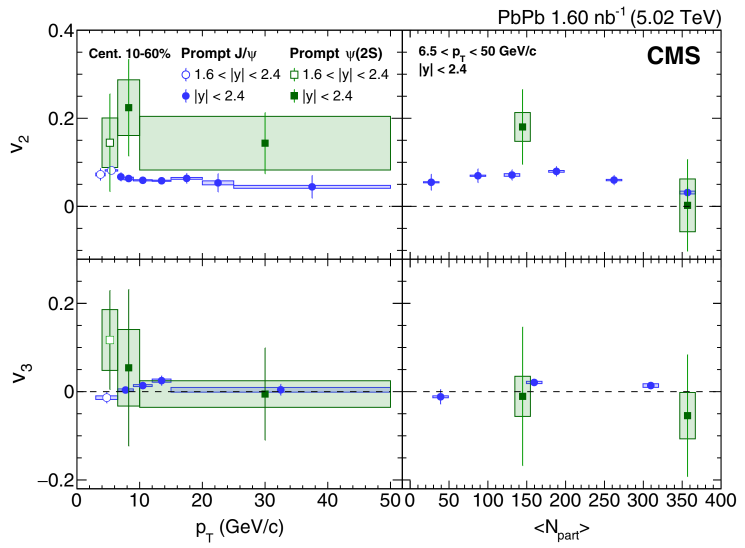

Figure 2. The v_2 (upper) and v_3 (lower) values as functions of p_T (left) and $\langle N_{part} \rangle$ (right) for prompt J/ψ (blue circles) and prompt ψ(2S) (green squares). The results for $p_T < 6.5$ and $p_T > 6.5$ GeV/c are diplayed in the rapidity range of $1.6 < |y| < 2.4$ and $|y| < 2.4$, respectively (left panel). The results for p_T bins for the right panel is 6.5–50 GeV/c and rapidity of $|y| < 2.4$. The vertical bars denote the statistical uncertainties, and the rectangular bands show the systematic uncertainties.

in heavy ion collisions. These J/ψ and ψ(2S) meson measurements provide new insights in the dynamics and in-medium effects of charmonia in heavy ion collisions.

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