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Measurement of quarkonium elliptic flow in pPb collisions at 8.16 TeV with the CMS detector

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Abstract. The second-order Fourier coefficients (v_2) of Υ(1S) and J/ψ mesons in high-multiplicity pPb collisions are studied using data collected by the CMS experiment at a nucleon-nucleon center-of-mass energy of 8.16 TeV. The dimuons used to reconstruct the quarkonium states are correlated with charged hadrons using the long-range two-particle correlation technique. The measurement of the Υ(1S) v_2 is reported for the first time in small collision systems. The results are discussed in terms of collectivity and modification of heavy quarks.

1 Introduction

Strong azimuthal correlations in nucleus-nucleus collisions are observed at the BNL RHIC [1, 2] and the CERN LHC facilities [3, 4]. These correlations are understood to arise from the creation of a strongly interacting medium, called quark-gluon plasma (QGP), that exhibits nearly ideal hydrodynamic behavior [5]. Similarly, long-range correlations have been also observed in high particle multiplicity events in smaller collision systems, such as proton-lead (pPb) collisions [6, 7].

Heavy quarks (charm and bottom) are particularly useful to probe such QGP-like signatures as they are produced in the early stages of heavy ion collisions and experience the entire medium evolution [8]. In lead-lead (PbPb) collisions, significant elliptic flow (v_2) signals have been measured for J/ψ mesons [9] while the v_2 values are found to be consistent with zero for Υ(1S) and Υ(2S) mesons [10], indicating different collective behavior for charmonia and bottomonia.

This contribution reports the measurements of the J/ψ mesons v_2 based on long-range, two-particle correlations in high-multiplicity pPb collisions at a center-of-mass energy per nucleon pair of $\sqrt{s_{NN}} = 8.16$ TeV. At the same $\sqrt{s_{NN}}$, the Υ(1S) meson v_2 is measured for the first time in small collision systems. The results provide unique information to the collective dynamics of heavy quarks in small collision systems.

2 Event Selection

This analysis uses pPb collision data collected with the CMS detector in 2016, with an integrated luminosity of 186 nb^{-1} [11]. The detailed description of the CMS detector can be found in Ref. [12]

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The results are reported for high-multiplicity events $185 \leq N_{\mathrm{trk}}^{\mathrm{offline}} < 250$ ($70 \leq N_{\mathrm{trk}}^{\mathrm{offline}} < 300$) for J/ψ (Υ(1S)) mesons, where $N_{\mathrm{trk}}^{\mathrm{offline}}$ is the number of charged particle tracks with $|\eta| < 2.4$ and $\mathrm{p_T} > 0.4$ GeV/c. Low-multiplicity events $N_{\mathrm{trk}}^{\mathrm{offline}} < 35$ ($N_{\mathrm{trk}}^{\mathrm{offline}} < 50$) for J/ψ (Υ(1S)) are also used to estimate the nonflow contribution, e.g., residual back-to-back jet-like correlations.

In this analysis, muons are reconstructed by extrapolating tracks from the silicon tracker to match a hit on at least one segment of the muon detectors. The muons are selected to be in $|\eta^{\mu}| < 2.4$ and $p_T^{\mu} > 3.0$ (3.5) GeV/c for J/ψ (Υ(1S)), to ensure the high efficiency for the reconstructed dimuons.

3 Analysis

In this analysis, the long-range ($|\Delta\eta| > 1$) two-particle correlation technique [6, 13] is used. The dimuons are used as the "trigger" particles, and are matched with "associated" charged particles with $|\eta| < 2.4$ and $0.3 < p_T < 3$ GeV/c.

The per-trigger-particle associated yield distribution is defined as

$$\frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N^{\mathrm{pair}}}{\mathrm{d}\Delta\eta \mathrm{d}\Delta\phi \Delta m_{\mu+\mu-} \Delta \mathrm{p_T}} = B(0,0) \times \frac{S(\Delta\eta, \Delta\phi, \Delta m_{\mu+\mu-}, \Delta \mathrm{p_T})}{B(\Delta\eta, \Delta\phi, \Delta m_{\mu+\mu-}, \Delta \mathrm{p_T})}, \tag{1}$$

where $\Delta\eta$ and $\Delta\phi$ are differences in η and ϕ of the pair, N_{trig} and N^{pair} are the number of trigger particles and the trigger-associated pairs in the event, respectively. S($\Delta\eta$, $\Delta\phi$) and B($\Delta\eta$, $\Delta\phi$) represents the yield of same-event pairs and yield of mixed-event pair.

The two-dimensional (2-D) distributions are projected onto the $\Delta\phi$ axis and the azimuthal anisotropy harmonics are determined from a Fourier decomposition,

$$\frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N^{\mathrm{pair}}}{\mathrm{d}\Delta\eta \mathrm{d}\Delta\phi} = \frac{N_{\mathrm{assoc}}}{2\pi} \left\{ 1 + \sum_n 2 V_{n\Delta} \cos(n\Delta\phi) \right\}, \tag{2}$$

where $V_{n\Delta}$ are the Fourier coefficients and N_{assoc} represents the total number of pairs per trigger particle for a given ($\mathrm{p_T}^{\mathrm{trig}}$, $\mathrm{p_T}^{\mathrm{assoc}}$) bin.

Signals and background components are used to fit the dimuon invariant mass ($m_{\mu^+\mu^-}$) distribution, and the fraction α of signal, as a function of $m_{\mu^+\mu^-}$, is defined as

$$\alpha(m_{\mu^+\mu^-}) = \mathrm{Sig}(m_{\mu^+\mu^-}) / (\mathrm{Sig}(m_{\mu^+\mu^-}) + \mathrm{Bkg}(m_{\mu^+\mu^-})). \tag{3}$$

The V_2 of dimuon as a function of the invariant mass $V_2^{\mathrm{Sig+Bkg}}(m_{\mu^+\mu^-})$ is fitted using

$$V_2^{\mathrm{Sig+Bkg}}(m_{\mu^+\mu^-}) = \alpha(m_{\mu^+\mu^-}) V_2^{\mathrm{Sig}} + (1 - \alpha(m_{\mu^+\mu^-})) V_2^{\mathrm{Bkg}}(m_{\mu^+\mu^-}). \tag{4}$$

Here, the signal (V_2^{Sig}) represents the V_2 of each dimuon resonance. The V_2 of background $V_2^{\mathrm{Bkg}}(m_{\mu^+\mu^-})$ is described by a polynomial function.

Contributions from jets are subtracted using the low-multiplicity subtraction method developed in Ref. [14] as

$$V_2^{\mathrm{sub}} = V_2^{\mathrm{Sig}}(\mathrm{high}) - V_2^{\mathrm{Sig}}(\mathrm{low}) \times \frac{N_{\mathrm{assoc}}(\mathrm{low})}{N_{\mathrm{assoc}}(\mathrm{high})} \times \frac{J_{\mathrm{jet}}(\mathrm{high})}{J_{\mathrm{jet}}(\mathrm{low})}, \tag{5}$$

where J_{jet} represents the near-side jet yield as the integral in the short-range region ($|\Delta\eta| < 1$). The ratio $J_{\mathrm{jet}}(\mathrm{high})/J_{\mathrm{jet}}(\mathrm{low})$, is introduced to account for the enhanced jet correlations resulting from the multiplicity selection. The associated ratio, $N_{\mathrm{assoc}}(\mathrm{low})/N_{\mathrm{assoc}}(\mathrm{high})$ accounts for the enhanced jet yield due to the difference of the associated track yield.

Finally, to determine the dimuon v_2 values, factorization is assumed where the V_2 value is taken as the product of single-particle v_2 value for the trigger particle and the associated charge hadrons, with

$$v_2^{sub}({p_T}^{\mathrm{trig}}) = \frac{V_2^{\mathrm{sub}}({p_T}^{\mathrm{trig}}, {p_T}^{\mathrm{assoc}})}{\sqrt{V_2^{\mathrm{sub}}({p_T}^{\mathrm{assoc}}, {p_T}^{\mathrm{assoc}})}}. \quad (6)$$

4 Results

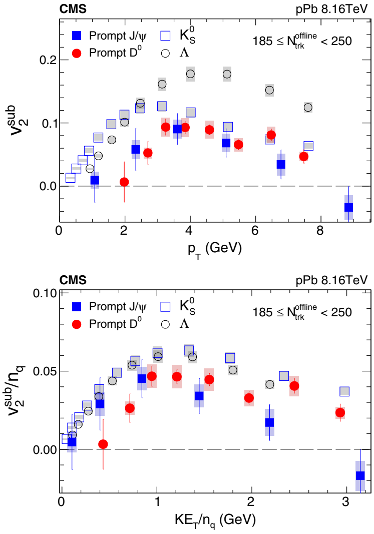

Figure 1. (Upper) The p_T-dependent v_2^{sub} values for prompt J/ψ mesons at forward rapidities ($1.4 < |y_{\mathrm{lab}}| < 2.4$) are compared to K_S^0 and Λ hadrons and prompt D^0 mesons at midrapidity ($|y_{\mathrm{lab}}| < 1.0$) [15] for pPb collisions at 8.16 TeV for $180 \leq N_{\mathrm{trk}}^{\mathrm{offline}} < 250$ where a low-multiplicity range with $N_{\mathrm{trk}}^{\mathrm{offline}} < 35$ to used estimate and correct for the dijet contribution [17]. (Lower) The n_q-normalize v_2^{sub} results. The vertical bars denote statistical uncertainties and the rectangular boxes systematic uncertainties.

Figure 1 shows the measured v_2^{sub} values in upper panel and nq-normalized v_2^{sub} in lower panel for prompt J/ψ meson where a clear positive v_2^{sub} is observed in $2 < p_T < 8$ GeV/c, comparing to D^0, K_S^0 and Λ particles. This results indicate weaker collective dynamics for charm quarks than for light quarks in small systems. On the other hand, Υ(1S) meson v_2^{sub} values are within one standard deviation of zero over the measured p_T range similar as the results in PbPb collisions shown in Fig. 2 (left). The consistency of v_2^{sub} values with zero over the entire p_T region suggests that the collectivity of bottom quarks does not strongly depends on the difference of the medium path length. In the comparison with J/ψ mesons, as shown in Fig. 2 (right), a discrepancy has been found in $3 < p_T < 6$ GeV/c. The different v_2^{sub} values for the two quarkonium states indicates different collective behavior of charm and bottom quarks in pPb collisions.

5 Summary

The elliptic flow (v_2^{sub}) of J/ψ and Υ(1S) mesons is measured as a function of transverse momentum (p_T) in high-multiplicity proton-lead (pPb) collision events at a center-of-mass

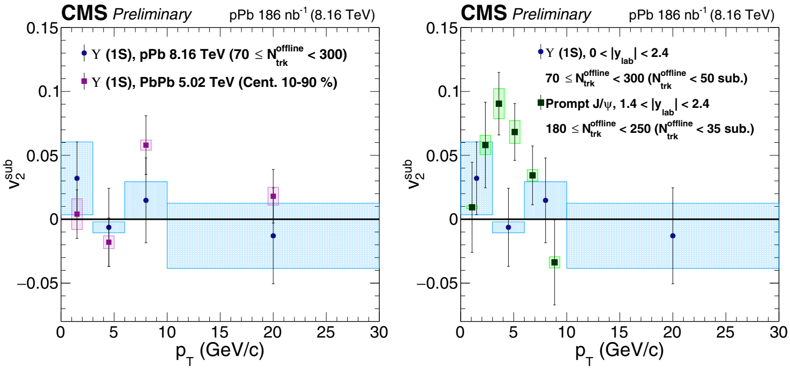

Figure 2. (Left) The $\mathrm{p_T}$ dependent v_2^{sub} values for ϒ(1S) mesons [16] are compared to the corresponding results from PbPb collisions at 5.02 TeV, measured within the 10–90% centrality range [10]. (Right) The same distribution is also compared with the v_2^{sub} values for prompt J/ψ mesons within $1.4 < |\mathrm{y_{lab}}| < 2.4$ in pPb collisions at 8.16 TeV for $180 \leq N_{\mathrm{trk}}^{\mathrm{offline}} < 250$, where a low-multiplicity range of $N_{\mathrm{trk}}^{\mathrm{offline}} < 35$ is used estimate and account for the dijet contribution [17]. The vertical bars denote statistical uncertainties and the rectangular boxes systematic uncertainties, while the widths of the boxes represent the $\mathrm{p_T}$ bin ranges.

energy per nucleon pair of $\sqrt{s_{NN}} = 8.16$ TeV. The v_2^{sub} values are reported for $0.2 < \mathrm{p_T} < 10$ GeV$/c$ and $0 < \mathrm{p_T} < 30$ GeV$/c$ for J/ψ and ϒ(1S) mesons, respectively. The ϒ(1S) meson v_2^{sub} is reported for the first time in pPb collisions. A sizable v_2^{sub} has been found for the J/ψ meson in mid-$\mathrm{p_T}$ region, while the ϒ(1S) meson v_2^{sub} is consistent with zero in the overall studied $\mathrm{p_T}$ region. This finding hints to different in-medium effects for charm and bottom quarks in pPb collisions which provides important constraints to the study of heavy flavor dynamics in small collision systems.

References

[1] STAR Collaboration, Phys. Rev. Lett. **95**, 152301 (2005)
[2] PHOBOS Collaboration, Phys. Rev. Lett. **104**, 062301 (2010)
[3] ALICE Collaboration, Phys. Rev. Lett. **105**, 252302 (2010)
[4] CMS Collaboration, Phys. Rev. C **87**, 014902 (2013)
[5] C. Gale, S. Jeon, B. Schenke, Int. J. Mod. Phys. A **28**, 1340011 (2013)
[6] CMS Collaboration, Phys. Lett. B. **718**, 795 (2013)
[7] ALICE Collaboration, Phys. Lett. B **719**, 29 (2013)
[8] P. Braun-Munzinger, J. Phys. G **34**, S471 (2007)
[9] CMS Collaboration, Eur. Phys. J. C **77**, 252 (2017)
[10] CMS Collaboration, Phys. Lett. B **819**, 136385 (2021)
[11] CMS Collaboration, CMS-PAS-LUM-17-002, (2018)
[12] CMS Collaboration, JINST **3**, S08004 (2008)
[13] CMS Collaboration, JHEP **07**, 076 (2011)
[14] CMS Collaboration, Phys. Lett. B **724**, 213 (2013)
[15] CMS Collaboration, Phys. Rev. Lett. **121**, 082301 (2018)
[16] CMS Collaboration, CMS-PAS-HIN-21-001, (2022)
[17] CMS Collaboration, Phys. Lett. B **790**, 172 (2019)