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Elliptic flow of J/ψ at forward rapidity in Pb-Pb collisions at 2.76 TeV with the ALICE experiment

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Abstract

We present the elliptic flow of inclusive J/ψ measured in the $\mu^+\mu^-$ channel at forward rapidity ($2.5 < y < 4.0$), down to zero transverse momentum, in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV with the ALICE muon spectrometer. The $p_{\rm T}$ dependence of J/ψ v_2 in non-central (20%-60%) Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV is compared with existing measurements at RHIC and theoretical calculations. The centrality dependence of the $p_{\rm T}$-integrated elliptic flow, as well as the $p_{\rm T}$ dependence in several finer centrality classes is presented.

1. Introduction

Charmonium production in heavy ion collisions has been studied at different energies and with different collision systems, ever since the J/ψ suppression induced by color screening of its constituent quarks was proposed as a signature of the formation of a quark gluon plasma (QGP) in heavy-ion collisions [1]. The recent measurement of the J/ψ production in Pb-Pb collisions at forward rapidity performed by ALICE at the LHC [2] clearly showed less suppression compared with SPS and RHIC results [3, 4]. At RHIC energies, the preliminary result from the STAR collaboration showed a J/ψ elliptic flow in Au-Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV [5] consistent with zero within uncertainties in the measured $p_{\rm T}$ range (0-10 GeV/c). A non-zero measurement of quarkonium elliptic flow is especially promising at the Large Hadron Collider (LHC) where the high energy density of the medium and the large number of $c\bar{c}$ pairs produced in Pb-Pb collisions is expected to favor the flow development and regeneration scenarios.

2. Data analysis and results

The ALICE detector is described in [6]. At forward rapidity ($2.5 < y < 4.0$) the production of quarkonium states is measured in the muon spectrometer down to $p_{\rm T} = 0$. The data sample used for this analysis corresponds to 17 M dimuon unlike sign (MU) triggered Pb-Pb collisions collected in 2011. It corresponds to an integrated luminosity $L_{\rm int} \approx 70\ \mu{\rm b}^{-1}$. The event and muon track selection are the same as described in [7], except for an additional requirement of the event vertex position $|Z_{\rm vtx}| < 10$ cm to ensure a flat event plane distribution. J/ψ candidates are formed by combining pairs of opposite-sign (OS) tracks reconstructed in the geometrical acceptance of the muon spectrometer.

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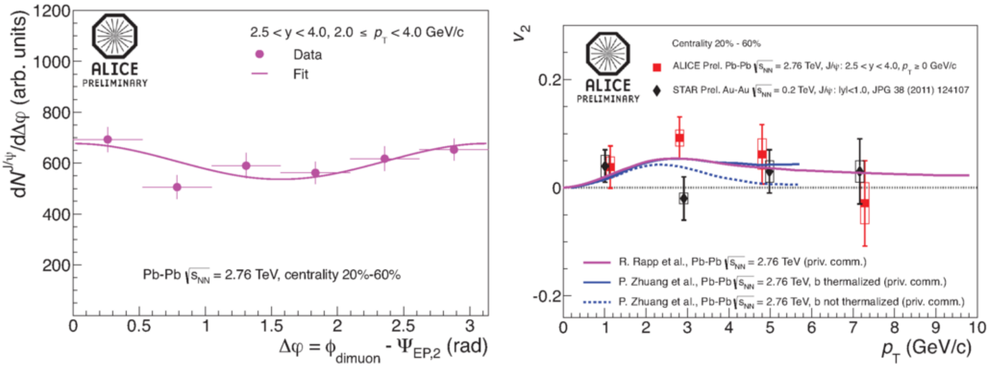

Figure 1: Left: v_2 extraction with the event plane method in which the J/ψ raw yield is plotted as a function of $\Delta\varphi$ using a fit to the data with $dN^{J/\psi}/d\Delta\varphi = A \times (1 + 2v_2^{obs} \cos 2\Delta\varphi)$. Right: Inclusive J/$\psi$ v_2 in the centrality bin 20%-60% as a function of p_T. A comparison to STAR results and to two parton transport model calculations [10, 11] are shown. The vertical bars show the statistical uncertainties, and the boxes indicate the point-to-point uncorrelated systematic uncertainties, which are dominated by the signal extraction.

The J/ψ v_2 is measured using event plane based methods [8]. To make a direct comparison with lower energy measurements, the inclusive J/ψ v_2 (p_T) was calculated in the same centrality range 20%-60% as at RHIC [5], as discussed in detail in [9]. The v_2 is extracted by fitting the J/ψ raw yield as a function of $\Delta\varphi = \phi_{dimuon} - \Psi_{EP,2}$ with $dN^{J/\psi}/d\Delta\varphi = A \times (1 + 2v_2^{obs} \cos 2\Delta\varphi)$, where A is a normalization constant (the standard event plane method), as shown in Fig. 1 (left panel). At LHC, the event-plane-resolution-corrected v_2 of J/ψ with $2 < p_T < 4$ GeV/c is different from the STAR preliminary measurement which is compatible with zero in all the measured p_T range, as shown in Fig. 1 (right panel). Two model calculations based on transport mechanism which include a J/ψ regeneration component from deconfined charm quarks in the medium [10, 11] are compared with data. These two models differ mostly in the rate equation controlling the J/ψ dissociation and regeneration. In both models about 50% of the produced J/ψ mesons originate from regeneration in QGP in the most central collisions. On one hand, thermalized charm quarks in the medium will transfer a significant elliptic flow to regenerated J/ψ. The maximum v_2 at $p_T \approx 2.5$ GeV/c results from a dominant contribution of regeneration at lower p_T with respect to the initial J/ψ component. Both models are able to qualitatively describe J/ψ $v_2(p_T)$ data as both were also able to describe the earlier R_{AA} measurement [2].

Consistent results in the same centrality bin are obtained with an invariant mass fit technique, in which we fit the $v_2 = \langle \cos 2\Delta\varphi \rangle$ vs. invariant mass ($m_{\mu\mu}$) as described in [12]. The method involves calculating the v_2 of the OS dimuons as a function of $m_{\mu\mu}$ and then fitting the resulting v_2 ($m_{\mu\mu}$) distribution using: $v_2(m_{\mu\mu}) = v_2^{sig}\alpha(m_{\mu\mu}) + v_2^{bkg}(m_{\mu\mu})[1 - \alpha(m_{\mu\mu})]$, where v_2^{sig} is the J/ψ elliptic flow and v_2^{bkg} is the background flow (parametrized using a second order polynomial function in this analysis). $\alpha(m_{\mu\mu}) = S/(S + B)$ is the ratio of the signal over the sum of the signal plus background of the $m_{\mu\mu}$ distributions. $\alpha(m_{\mu\mu})$ is extracted from fits to the OS invariant mass distribution in each p_T and centrality class. The OS dimuon invariant mass distribution was fitted with a Crystal Ball (CB) function to reproduce the J/ψ line shape, and either a third order polynomial or a variable width gaussian to describe the underlying continuum. The CB function connects a Gaussian core with a power-law tail [13] at low mass to account for energy loss fluctuations and radiative decays. The combination of several CB and underlying continuum

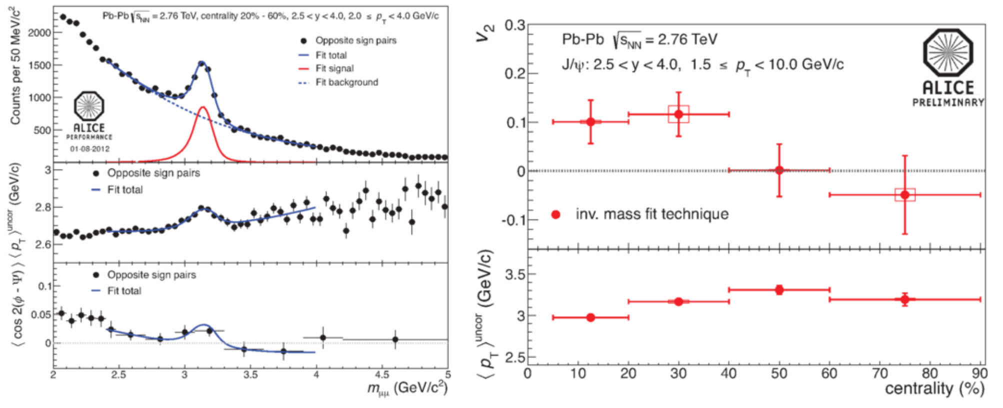

Figure 2: Left: $\langle p_T \rangle^{\text{uncor}}$ and v_2 extraction with the fit invariant mass technique. Right: Event plane resolution corrected J/ψ v_2 as a function of centrality of J/ψ with $p_{\text{T}} \geq 1.5$ GeV/c. The vertical bars show the statistical uncertainties, and the boxes indicate the point-to-point uncorrelated systematic uncertainties, which are dominated by the signal extraction.

parametrization were tested to assess the signal and the related systematic uncertainties. The J/ψ v_2 in each p_{T} and centrality class was determined as the average of the v_2^{sig} obtained by fitting $v_2(m_{\mu\mu})$ with various background shapes, while the corresponding systematic uncertainties were defined as the *r.m.s.* of these results. A similar method is used to extract the uncorrected average transverse momentum $\langle p_{\text{T}} \rangle^{\text{uncor}}$ of the reconstructed J/ψ in each centrality and p_{T} class. Fig. 2 (left panel) shows typical fits of the OS invariant mass distribution (top left), the $\langle \cos 2(\phi - \Psi_{\text{EP},2}) \rangle$ (bottom left) and $\langle p_{\text{T}} \rangle^{\text{uncor}}$ (middle left) as a function of $m_{\mu\mu}$ in the 20%-60% centrality class. The obtained J/ψ $\langle p_{\text{T}} \rangle^{\text{uncor}}$ is used to locate the ALICE points when plotted as a function of transverse momentum.

Fig. 2 (top right) shows v_2 for inclusive J/ψ with $p_{\text{T}} \geq 1.5$ GeV/c as a function of centrality. The vertical bars show the statistical uncertainties while the boxes indicate the point-to-point uncorrelated systematic uncertainties from the signal extraction. The measured v_2 depends on the p_{T} distribution of the reconstructed J/ψ. Therefore, $\langle p_{\text{T}} \rangle^{\text{uncor}}$ of the reconstructed v_2 is also shown in Fig. 2 (bottom right) as a function of centrality. For the two most central bins, 5%-20% and 20%-40% the inclusive J/ψ v_2 for $p_{\text{T}} \geq 1.5$ GeV/c are 0.101 ± 0.044(stat.) $\pm$ 0.003(syst.) and 0.116 ± 0.045(stat.) $\pm$ 0.017(syst.), respectively. For the two most peripheral bins the v_2 is consistent with zero within uncertainties. Although there is a small variation with centrality, the $\langle p_T \rangle^{\text{uncor}}$ stays in the range (3.0, 3.3) GeV/c indicating that the bulk of the reconstructed J/ψ are in the same intermediate p_{T} range for all centralities. Thus, the observed centrality dependence of the v_2 for inclusive J/ψ with $p_{\text{T}} \geq 1.5$ GeV/c does not result from any bias in the sampled p_{T} distributions.

Fig. 3 shows the inclusive J/ψ $v_2(p_{\text{T}})$, using the invariant mass fit technique, for central, semi-central and peripheral Pb-Pb collisions at 2.76 TeV. In the semi-central (20%-40%) case, taking into account statistical and systematic uncertainties, the combined significance of a non-zero v_2 in $2 \leq p_{\text{T}} < 6$ GeV/c range is 3σ. At lower and higher transverse momentum the inclusive J/ψ v_2 is compatible with zero within uncertainties. In most central (5%-20%) and peripheral (40%-60%) case, the large uncertainties do not allow any firm conclusion.

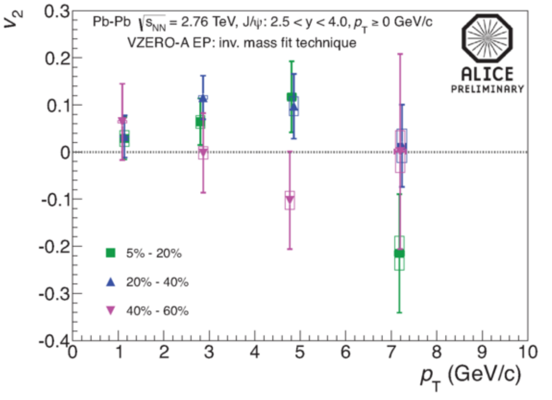

Figure 3: J/ψ v_2 as a function of p_T in various centrality bins: 5%-20%, 20%-40% and 40%-60%. The vertical bars show the statistical uncertainties, and the boxes indicate the point-to-point uncorrelated systematic uncertainties from the signal extraction.

3. Summary and conclusion

In summary, we reported the ALICE measurement of inclusive J/ψ v_2 at forward rapidity in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. For non-central (20%-60%) collisions a hint of a non-zero J/ψ elliptic flow is observed in the intermediate p_T range in contrast to the zero v_2 observed at RHIC. Indication of a non-zero J/ψ v_2 is also observed in semi-central (20%-40%) collisions at intermediate p_T. The integrated v_2 of J/ψ with $p_T > 1.5$ GeV/c in 5%-40% collisions also shows a non-zero behavior. These measurements complement our earlier results on J/ψ suppression, where a smaller suppression was seen at low transverse momentum at the LHC compared to RHIC [2, 7, 14]. Both results taken together could indicate that a significant fraction of the observed J/ψ are produced from a (re)combination of the initially produced charm quarks. Our J/ψ elliptic flow results in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV are in qualitative agreement with transport models that are able to reproduce our J/ψ R_{AA} measurement.

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