Commnets on “Quarkonia suppression in PbPb collisions at $\sqrt{s}_{NN} = 2.76$ TeV”

GENERAL PROBLEMS WITH MANUSCRIPT

I. FIGURES

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All above suggestions are implemented.

II. REFERENCES

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Report of the Referee – CX10370/Kumar

First of all, I would like to apologize to the authors for the delay to produce this report.

This paper discusses the important topic of quarkonium (J/psi, Upsilon, Upsilon') suppression in PbPb collisions at the LHC. The suppression is calculated in a model which include various hot medium effects (gluon dissociation, recombination, pion dissociation) in addition to nuclear PDF corrections. The results are compared to ALICE and CMS measurements.

I list below several comments and points which should be addressed before I can recommend the paper to be published in Physical Review C.

We thank the referee for his suggestions. We have incorporated most of the suggestions. Some of them required considerable work to improve the manuscript.

III. NUCLEAR PDF (NPDF) EFFECTS

1. The authors use only the central set of the EPS09 parametrization instead of calculating the EPS09 uncertainty. Therefore it is difficult for the reader to assess the uncertainty coming from nuclear PDF corrections at the LHC. If it is numerically too difficult to compute the EPS09, they could use for instance another nPDF set, e.g. the recent DSSZ.

   We include uncertanity due to all sets of EPS09 parametrization of nPDFs. This uncertanity band is shown in figures with the central value of CNM effects.

2. There is little detail on how nPDF effects are computed. For instance, it would be interesting to know what is the hard scale used in the calculation. In particular, does it depend on pT? Also, it is not clear to me how the heavy-quarkonium production cross section is computed. I understand that heavy quark production is computed using Refs. [26,27] but one needs a specific model in order to compute the production of Q-Qbar bound states. Is it CEM?

   We have recalculated all the cross sections presented in the table I using all new sets of PDFs and parameters tuned to reproduce the measured data. We have taken help from Prof Ramona Vogt and hence she has agreed to be author of the new version. The details are given in paper are presented as follows:

The heavy quark production cross section are calculated to NLO in pQCD using the CT10 parton densities [1]. The mass and scale parameters used for open and hidden heavy flavor production are obtained by fitting the energy dependence of open heavy flavor production to the measured total cross sections [2, 3]. Those obtained for open charm are $m_c = 1.27 \pm 0.09$ GeV, $\mu_F/m_{T\,c} = 2.10^{+2.55}_{-0.85}$, and $\mu_R/m_{T\,c} = 1.60^{+0.11}_{-0.12}$ [2]. The botttom quark mass and scale parameters are $m_b = 4.65 \pm 0.09$ GeV, $\mu_F/m_{T\,b} = 1.40^{+0.75}_{-0.47}$, and $\mu_R/m_{T\,b} = 1.10^{+0.26}_{-0.19}$ [3]. The quarkonium production cross sections are calculated in the color evaporation model with normalizations determined from fitting the scale parameter to the shape of the energy-dependent cross sections [2, 3]. The resulting uncertainty bands are smaller than those obtained with the fiducial parameters used in Ref. [4]. We note that the new results are within the uncertainties of those Ref. [4]. Indeed, the charm cross sections reported at the LHC agree better with the new values of the mass and scale than the central value of $m_c = 1.5$ GeV, $\mu_F/m_T = \mu_R/m_T = 1$

[1] H. L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin and C.-P. Yuan, "New parton distributions for collider physics," Phys. Rev. D **82**, 074024 (2010).

[2] R. E. Nelson, R. Vogt and A. D. Frawley, 'Narrowing the uncertainty on the total charm cross section and its effect on the J/ψ cross section," Phys. Rev. C **87**, no. 1, 014908 (2013).

[3] R. Nelson, R. Vogt and A. D. Frawley, in preparation.

[4] M. Cacciari, P. Nason and R. Vogt, "QCD predictions for charm and bottom production at RHIC," Phys. Rev. Lett. **95**, 122001 (2005).

3. The nPDF effects seem to have a small but visible dependence on the centrality of the collision, however the default EPS09 set has no impact parameter (spatial) dependence. The authors should clarify the origin of this Npart dependence. I am also quite surprised to see that in the CMS kinematics, pT $\geq$ 6.5 GeV, the nPDF effects lead to an enhancement (due to anti-shadowing), I was not expecting this because of the rather small values of x_{Bj} typically probed at the LHC.

The EPS09 set gives p_T dependent shadowing factors and uncertainties. To get N_{Part} dependence the p_T integrated shadowing factor is linearly scaled by the variable d ($=N_{\mathrm{Coll}}$ / ($N_{\mathrm{Part}}\times 0.5$)) which mimics the density in the overlapping zone using minimum bias value and pp value which is 1.

4. This is a detail but it is more appropriate to mention 'nuclear PDF effects' instead of 'shadowing' which only applies to the small-x depletion of the PDF in nuclei (one can see the effect of anti-shadowing and the EMC effects in Fig. 5 left and Fig. 6 right).

   We agree with it and in the figures we mention CNM Effects (Cold Nuclear Matter Effects) and also change the title of section 2.

IV. PION DISSOCIATION

1. The authors use an arbitrary cross section of 1 mb independently of the pion energy. They mention that this cross section is small, however this is very similar in magnitude to the gluon-quarkonium cross section, see Fig. 2. In order to have a consistent framework, the authors should rather use the pQCD quarkonium-pion cross section, directly accessible from the convolute the quarkonium-gluon cross section (Fig. 2) with the gluon distribution in a pion, see Refs. [16,33,34] (see e.g. Ref. [34] in which the quarkonium-pion cross section has a rapid variation with the pion energy).

   Following referee's suggestion we have reworked this section dealing with hadronic comover. The pion-Quarkonia cross section is calculated by convoluting the gluon-quarkonia cross section σ_D over the gluon distribution inside pion [38] as

$$\sigma_{\pi Q}(p_\pi) = \frac{p_+^2}{2(p_\pi^2 - m_\pi^2)} \int_0^1 dx\, G(x)\, \sigma_D(xp_+/\sqrt{2}) \tag{1}$$

   where $p_+ = (p_\pi + \sqrt{p_\pi^2 - m_\pi^2})/\sqrt{2}$. The gluon distribution $G(x)$ inside pion is given by GRV parameterization [42].

38 F. Arleo, P. B. Gossiaux, T. Gousset and J. Aichelin, Phys. Rev. D 65, 014005 (2002) [hep-ph/0102095].

42 M. Glueck, E. Reya, A. Vogt, Z. Phys. C**53** 651 (1992).

2. Apart from the energy dependence, the magnitude of the pion-J/ψ and pion-Υ cross section should not be the same, the latter being smaller than the former by a factor 4-5.

   This problem is taken care care when we use above procedure.

3. I fail to understand to understand why pion dissociation is much less effective for Υ than for J/ψ (compare Fig. 6 left and Fig. 7 left), since the cross section is taken to be equal. Is it due to the different p_T spectrum?

   It was due to different p_T spectra. But now the cross section for Υ is smaller as compared to J/ψ due to tighter binding of Υ.

4. Also, what is assumed for the quarkonium(2S)-pion cross section? It should be significantly larger than the quarkonium(1S)-pion cross section. As a matter of fact, the comover effect seems more pronounced on 2S states (compare Fig. 7 left and right) but nothing is said on the comover effects on 2S in the model.

   The comover effect on Υ(2S) is calculated as per above procedure now.

V. HYDRODYNAMICAL EVOLUTION

1. The authors assume a transverse expansion of the medium, see Eq. (8). In non-central collisions, however, the expansion should depend on the azimuthal angle, leading to non-negligible elliptic flow. I think the authors should comment on that.

   There will be azimuthal-anisotropy with respect to reaction plane. But this effect will be averaged out over a large number of collisions.

VI. COMPARISON TO DATA

1. In order to have a meaningful comparison to data, I think the authors should try to quantify the uncertainty of their calculation. For instance, the most important effects in their model are gluon dissociation and recombination, which crucially depends on the quarkonium-gluon cross section. How would the predictions vary if they change the magnitude of this cross section (which is poorly known) by, say, a factor 1.5 or 2?

The dominant sources of the uncretainties come from the gluon quarkonia cross section and initial temperature (discussed in next point). We vary the quarkonium-gluon cross section by a factor of 0.5 and 1.5 arround the calculated value and obtain the variation in the final R_{AA} calculations.

2. Similarly, the magnitude on the medium energy density could be varied in order to give a feeling to the reader on the corresponding uncertainty on R_{AA}. Clearly the calculations are done for one set of parameters and assumptions, it's difficult to know how the predictions would change when those are varied.

   We calculate the initial temperature using measured charged particle density and assuming a value for τ_0. We change it in reasonably large range from 0.1 to 0.6 fm/c and the variation in R_{AA} is calculated. Both of these uncertainties are added in quadrature to obtain the band.

3. In this respect, many effects are included... but with uncertainty which are not quantified. Since the effects of nPDF or comover affect R_{AA} by at most 20%, I think it would make more sense not to include them at all. In particular, the authors include effects with magnitude 10-20% while other cold nuclear matter effects such as energy loss in nuclei prove much stronger (see e.g. 40% effects on J/psi in arXiv:1407.5054) but are not included.

   The uncertainites in the calculation are quantified. We still include CNM and comover effect. The prescriptions for change in the R_{AA} of quarkonia due to initial energy loss in nuclei are still evolving we have not included this effect. It can be included in a future work.

4. Also, the authors do not discuss the dissociation of heavy-quarkonium due to the Debye screening of the heavy-quark potential at finite temperature, which is historically the main effect discussed in Ref. [1]. Do they consider it to be negligible? This point would need to be discussed.

   The suppression of quarkonia can be understood in terms of gluon dissociation and/or color screening. There is more colour screening at higher temperature. The gluon dissociation will also be larger due to harder gluon momentum distribution. At higher temperature the gluon dissociation cross section can also increase due to colour screening and this effect must come in the uncertainty due to variation of the cross section.

5. Fig. 6 left and Fig. 7 left are a bit misleading because data points corresponding to two different kinematical regions are included, but only one calculation is provided and it is not possible to know which region it corresponds to.

   The calculations in this figure was for mid-rapidity. Now we have separated the forward rapidity and mid rapidity calculations in different figures.

6. The authors present a model for Υ(2S) and not for ψ(2S). I understand that for charmonia, and in particular 2S states, the pQCD cross section may not be valid but still it would be very interesting for the reader to know the model predictions. In particular, the CMS experiment reported on a very interesting behavior of ψ'/J/ψ in PbPb collisions, and it seems natural to wonder whether or not the possibly large recombination in the ψ' channel could compare to these data.

   Since the ψ(2S) cross-section is not reliable so we have avoided to speculate on the charmonia ratio.

VII. COMPARISON TO DATA

1. Finally, many details or references are missing. In particular, why $R_{0-5\%}$=0.92 R_{Pb}? What is the value of a_m? Which values are taken for m_c and m_b? It is also not clear to me why they need to compute the entropy S(tau) in Eqs. (10,11), I probably missed the point.

   The value of a_m is 5 for QGP. $R_{0-5\%}$=0.96 $R_{\rm Pb}$ is obtained by $R_{0-5\%} = R_{\rm Pb}\sqrt{N_{part,0-5}/N_{part,0}}$ where $N_{part,0}$ is number of participants in head on collision (b=0). The correct value is 0.96. First we get the initial entropy for 0-5% case from Eq. 11 and then use Eq. 10 to obtain entropy for other centralities using the experimental measurement of ratio.

2. On page 6, the reference to an experimental paper on dN/deta is missing.

   The Ref. 31 and 34 (new) are for ALICE. We have included the CMS reference [32] also.

3. On Fig. 3, what is the rapidity of the quarkonium states? Is it mid-rapidity? Maybe it would be more relevant to draw curves for a given quarkonium energy E instead of binning in pT. It would also be interesting to have the equivalent of Fig. 3 and 4 for 2S states.

   Fig. 3 shows the calculations in mid rapidity.

In conclusion, it would be valuable to address/answer these various points in a revised version of the manuscript before I can recommend its publication in Physical Review C.

We have done considerable work to improve the manuscript so that almost all of the suggestions are incorporated. The revised manuscript is submitted.

VIII. ADDITIONAL IMPROVEMENTS

1. We improved the calculations for the hevay flavour and quarkonia cross-sections. These calculations are improved by using CT10 PDFs also mass of charm and bottom quarks is tuned in such a way that it give better fitting to measured total charm production cross-section. Cross-sections and corresponding uncertainties are shown in the table I.

2. Figures 3 (a) and 3(b) have same y axis ranges now similarly y axis ranges of Figures 4 (a) and 4(b) is identical.

3. We changes the order of figures. Now mid rapidity measurements of CMS and ALICE for J/ψ nuclear modification factor is shown together in Figure 7(a) and 7(b). ALICE measurement in forward rapidity is shown separately in Figure 6. Similarly Υ measurements of CMS and ALICE are shown separately in Figure 8 and Figure 9 respectively.

4. A final reading of the paper was done and at several places language, articles, punctuations have been improved. Wherever additional sentences are put they are highlighted in blue color.