Report of Referee 1

In this paper the authors present a refit of quarkonium data in pp collisions based on the NRQCD formalism coupled with pQCD production amplitudes. The new aspect is essentially the inclusion of the new LHC data which, in many cases, leads to considerably different values of the NRQCD matrix elemnets compared to existing literature. By and large this is a reasonable work that can be published in JPG. However, several points have to be addressed prior to that.

Ans: We thank the referee for his/her comments. We address all the points and modify the manuscript as described below:

1. In the intorduction, a more broad representation of the literature should be given, e.g. for the use of quarkonia in heavy-ion collisions. I find it a bit overstated to claim that measuring their ratios for excited over ground states "has become the most important goals of Pb-Pb collisions at LHC".

   The discussions of heavy ion collisions are modified and references are updated as follows:

   The quarkonia yields are modified in the heavy ion collision due to QGP and cold nuclear matter effects which has been demonstrated for J/ψ and Υ in PbPb collisions [1–3]. The ratios of excited to ground state quarkonia yields are considered as better probes of QGP since the cold matter effects, which are similar for the ground and excited states, are expected to cancel in the ratio. At the LHC, the production of charmonium (J/ψ, ψ(2S)) and bottomonium (Υ(1S),Υ(2S),Υ(3S)) states has been studied in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and $\sqrt{s_{NN}} = 5.02$ TeV [4–9] showing the importance of quarkonia measurements in heavy ion collisions.

2. I am not sure the authors deliver on the promise made in the introduction of quantifying NLO corrections. The paragraph on top of page 13 is a bit thin in this regard, and seems to be contradictory (factor 3 vs. 2-3 orders of magnitude enhancement of the psi' cross sectoin).

The NLO corrections increase the total color-singlet J/ψ cross section by a factor of two, although at high p_T the corrections can enhance the production by 2-3 orders of magnitude. [11]. The NLO corrections to J/ψ production via S-wave color octet (CO) states ($^1S_0^{[8]}\,^3S_1^{[8]}$) are studied in Ref. [12] and the corrections to p_T distributions of both J/ψ yield and polarization are found to be small. We have given an estimate of uncertainty in the LDMEs due to enhancement of color-singlet J/ψ cross-section by a factor of three expected from NLO corrections.

First paragraph of page 13 is modified as follows:

Here the first error is due to fitting and the second error is obtained by enhancing the CS cross section 3 times. It is due to the fact that NLO corrections enhance the total color-singlet J/ψ production by a factor of 2 [11]. The NLO corrections to J/ψ production via S-wave color octet (CO) states ($^1S_0^{[8]}\,^3S_1^{[8]}$) are found to be small Ref. [12].

3. I believe that appendix A referred to in the text is missing altogether. It should be supplied.

   Appendix A is included in the new version of paper.

4. I am wondering why the authors cut off their fits at pt=5GeV. How is that choice motivated?

   It is known that the perturbative expansion calculations are not applicable to the regions with small transverse momentum. It is shown by previous NRQCD calculations [13] that the formalism for production works well only for large pT. If we use a lower pT cut off it would give a significantly larger χ^2/dof.

5. The chi^2/dof fit values of typical 2.5-3 are not very good. The authors should comment on that. For example, does that imply the breakdown of the NRQCD formalism, or the production cross sections, or else?

   The fitting method consist of simultaneous fitting of several (seven-eight) datasets covering different collision energies and different kinematic ranges. Our Chi^2 are comparable to other [13, 14] such analysis.

6. The summary is a bit too short. In addition to emphasizing the main discrepances of this work with existing literture, the authors should provide a more general perspetive of the implications of their results.

   We have extended the summary in the new manuscript.

7. I could not find some of the collision systems listed in Section 3 in the figures, for example 1.8TeV for chi$_c$ and 7 TeV LHCb result fot psi' Once the aboe points are satisfactorily addressed in the ms. it can be published.

   We have included these calculations in the new version of manuscript .

Report of Referee 2

The manuscript describes a leading-order fit of chi$_{c0}$, psi(2S) and J/psi NRQCD color-octet long distance matrix elements (CO LDMEs) to Tevatron and LHC hadroproduction data. The work is certainly done thoroughly, and, besides some minor misunderstandings, the article is clearly written. The article does however not fulfill JPhysG's criterion of having "new results that substantially advance their relevant field": Leading order fits of this kind have already been published 20 years ago. The only relevant difference to these early works seems to be the inclusion of the chi$_{c2}$/chi$_{c1}$ ratio in the chi$_{c0}$ CO LDME fit, which have only become available with the LHC. Current CO LDME fits are done at next-to-leading and include a much wider range of observables, including photoproduction data, eta$_c$ production rates and polarization observables on top of the observables used in the manuscript assessed here.

A LO NRQCD analysis is useful as it is straightforward and unique and once the parameters are obtained by fitting over large datasets it has excellent predictability power for unknown cross sections.

Report of Referee 3 (Adjudication report)

Dear Editors,

Although this work remains below the present technological state of the art, which is next-to-leading order as pointed out correctly by Referee B, it should still be of some interest. In fact, it present a comprehensive lowest-order analysis of hadroproduction data, including

very recent LHC data. The resulting long-distance matrix elements may be useful as input for LO analysis by other authors.

However, the authors are missing some relevant references that underline the current charmonium crisis of NRQCD factorization which has recently emerged in various studies:

1. The problem of performing a joint analysis of the e^+e^-, photoproduction, hadroproduction and polarization data:: arXiv:1212.2037 [hep-ph].

2. The problem of describing the eta$_c$ hadroproduction data on the basis of heavy-quark spin symmetyry:arXiv:1411.5287 [hep-ph]

3. The problem of describing double J/psi hadropoduction at large invariant masses and rapidity separations of the J/psi pair: arXiv:1609.02786 [hep-ph] Furthermore, they should add the following paper to Ref. 31 because it present the global fit: arXiv:1105.0820 [hep-ph]. I recommend that the discussion of the NRQCD crisis be substantiated and that these reference be properly cited.

   We have included following discussion regarding above points in the manuscript:

   Authors in Ref. [14] extracted leading color-octet LDMEs through a global fit to experimental data of unpolarized J/ψ production in pp, p$\overline{\text{p}}$, ep, $\gamma\gamma$, and e^+e^- collisions. The extracted LDMEs give excellent discription of the unpolarized J/ψ yields but fail to reproduce the polarization measured at CDF [15]. In another study [16], it is shown that the measured hadroproduction cross sections and the CDF polarization measurement [15] can be simultaneously described by NRQCD at NLO.

   Recently, the LHCb measurements of η_C production [17] is investigated from different points of views by several groups using NRQCD formalism [18–20]. Ref. [18] considered the η_c measurement as a challenge of NRQCD while Ref. [19] shows that the LHCb measurement results in a very strong constraint on the upper bound of the color-octet LDME of J/ψ. Refs. [20] obtain the color-singlet LDME for η_c by fitting the experiment data to obtain good discription of η_c production.

   The prompt double heavy quarkonium production is a sensitive testing ground for NRQCD factorization. The experiments at LHC recently published the measurement of double J/ψ production in proton-proton collision at $\sqrt{s} = 7$, 8 and 13 TeV [21–24].

Full NLO calculations including all color singlet and color octet contributions for this process in the NRQCD framework are not fully established yet. Authors in Ref [25] showed that the LO calculations of the prompt double J/ψ production by NRQCD formalism describes the data only qualitatively. Authors in Ref [26] present the NLO calculations for the color-singlet channel which describe the measured LHCb cross section reasonably well, but fail to reproduce the CMS measurements. The complicated situation suggests that, further study and phenomenological test of NRQCD is still an urgent task.

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