# Bottomonia production in NRQCD formalism

Kinkar Saha[1],* Vineet Kumar[2], Prashant Shukla[2], and Abhijit Bhattacharyya[1]
[1] *Dept. of Physics, University of Calcutta, Kolkata and*
[2] *Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai*

## Introduction

The quarkonia have been proved to be a viable tool to probe both perturbative and non-perturbative aspects of Quantum Chromodynamics (QCD). Because of the small velocity v of its massive constituents, the quarkonia states are qualitatively distinct from most other hadrons and non-relativistic treatment of such bound states thus becomes feasible. The NRQCD factorization scheme in this regard, is one of the most promising and reliable formalisms for analyzing the heavy quarkonia production[1]. The study of the differential charmonia production cross sections in high energy p+p collisions is completed using NRQCD formalism[2].

## Bottomonia Production in p+p collisions

Under the NRQCD formalism, the direct production cross-section of a resonance in a collision of two particles can be expressed in factorized form[3]. While the short distance contributions are calculated within the framework of perturbative QCD (pQCD), the Long Distance Matrix Elements (LDMEs) are estimated using fit to experimental measurements. In this work, we have calculated the production cross sections for $\Upsilon$ states using large set of measured data currently available at LHC energies [4–6] for both central and forward rapidities to constrain the LDMEs required for $\Upsilon$(3S) production. We have further estimated the LDMEs to predict $\Upsilon$(2S) production cross-section using data from CMS and ATLAS Collaborations[4–6] at $\sqrt{s} = 7$ and 13 TeV. For that purpose, we have used feed down contribution only from $\Upsilon$(3S) state. We are in process of including feed down contributions from all the applicable bottomonia states. In the limit $v << 1$, the production of quarkonium is based on the ${}^3S_1^{[1]}$ and ${}^3P_J^{[1]}$ ($J$ = 0,1,2) Color Singlet states, ${}^1S_0^{[8]}$, ${}^3S_1^{[8]}$ and ${}^3P_J^{[8]}$ Color Octet states. The differential cross section for the direct production of $\Upsilon$(3S) can be written as the sum of these contributions. In our calculations, we used the expressions for the short distance cross-sections from Refs.[7, 8].

## Results and discussions

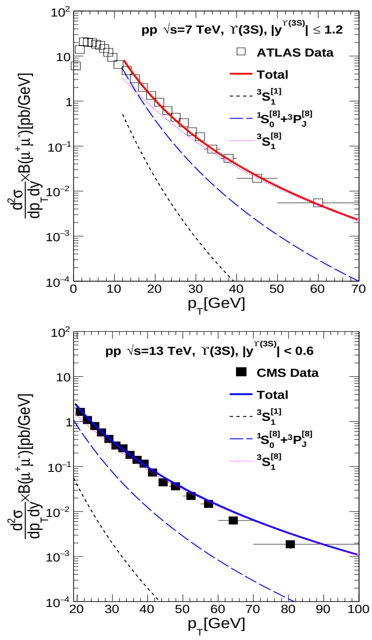


FIG. 1: The NRQCD calculations of production cross section of $\Upsilon$(3S) in p+p collisions at $\sqrt{s}$ = 7 and 13 TeV, compared with the measured data at CMS[4, 5] and ATLAS[6] experiments.

*Electronic address: saha.k.09@gmail.com

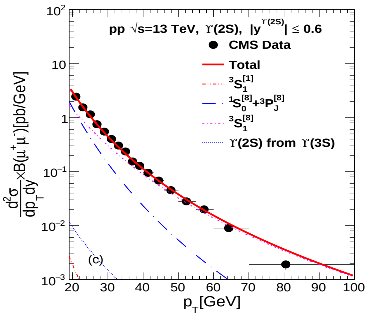


FIG. 2: The NRQCD calculations of production cross section of $\Upsilon$(2S) in p+p collisions at $\sqrt{s}$ = 7 and 13 TeV, compared with the measured data at CMS[5] experiment. Feed down contributions from $\Upsilon$(3S) has been considered.

$\Upsilon$(3S), the highest bound state in b$\overline{\text{b}}$ spectrum, must not have any feed down contribution. The CS LDMEs can be obtained by solving the non-relativistic wavefunctions[8]. For the CO LDMEs, experimental data are used to constrain them. Figure 1 shows the NRQCD calculations of production cross section of $\Upsilon$(3S) in p+p collisions as a function of transverse momentum found from the combined fitting of measured data in CMS[4, 5] and ATLAS[6] detectors at LHC. Table I shows the corresponding values of CS and CO LDMEs, as extracted. The $\chi^2/dof$ is ~3.8. Our values of LDMEs are compatible with those obtained in[9]. We however have significantly improved on the errors present on the values of LDMEs by using combined fitting of large datasets currently available at LHC energies. Further investigation in terms of accuracy is however in progress. Figure 2 shows the estimation of $\Upsilon$(2S) production cross-section using combined fitting of the experimental data from CMS[4, 5] and ATLAS[6] measurements at 7 and 13 TeV, with feed down contribution only from $\Upsilon$(3S). We plan to present the detailed study including feed down from all higher states. The values for LDMEs so far obtained are provided in Table I with a combined $\chi^2/dof$ of ~4.0. Further investigation in this direction is however needed to be conclusive and that is in order.

| $\Upsilon$ | $M_L([^3S_1]_1)$ | $M_L([^3S_1]_8)$GeV$^3$ | $M_L([^1S_0]_8)$GeV$^3$ |
|---|---|---|---|
| (3S) | 4.3GeV$^3$ | 0.0563±0.0007 | 0.0197±0.0005 |
| (2S) | 4.5GeV$^3$ | 1.2938±0.0429 | 0.8129±0.0465 |

TABLE I: CS and CO LDMEs for $\Upsilon$(3S) and $\Upsilon$(2S) extracted from the combined fitting of latest LHC data[4–6].

## Summary

We have calculated the differential production cross-section of $\Upsilon$(3S) and $\Upsilon$(2S) mesons as a function of transverse momentum. Presently available data at LHC energies are used to obtain the values of color octet LDMEs. Feed down from $\Upsilon$(3S) has only been considered here to produce results for $\Upsilon$(2S). A further rigorous study in this direction along with the same for $\Upsilon$(1S) is in progress.

KS acknowledges DST-SERB for financial support under NPDF project no. PDF/2017/002399. Authors thank BRNS for financial support.

## References

[1] G. T. Bodwin, E. Braaten, and G. P. Lepage, Phys. Rev. D **51** 1125 (1995), [Erratum-ibid. D **55** 5853 (1997)].
[2] V. Kumar and P. Shukla, J. Phys. G **44** 085003 (2017).
[3] B. Gong, J-X Wang, and H-F Zhang, Phys. Rev. D **83** 114021 (2011).
[4] V. Khachatryan *et al.* [CMS Collaboration], Phys. Lett. B **749**, 14 (2015).
[5] V. Khachatryan *et al.* [CMS Collaboration], Phys. Lett. B **780**, 251 (2018).
[6] G. Aad *et al.* [ATLAS Collaboration], Phys. Rev. D **87**, no. 5, 052004 (2013).
[7] R. Baier and R. Ruckl, Z. Phys. C **19**, 251 (1983).
[8] P. L. Cho and A. K. Leibovich, Phys. Rev. D **53**, 150 (1996).
[9] R. Sharma and I. Vitev, Phys. Rev. C **87**, 044905 (2013); E. Braaten, S. Fleming, and A. K. Leibovich, Phys. Rev. D **63** 094006 (2001).