High p$_T$ Υ(3S) production at LHC energies

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Introduction

The quarkonia ($Q\bar{Q}$) have provided useful tools for probing both perturbative and non-perturbative aspects of Quantum Chromodynamics (QCD). The quarkonia states are qualitatively different from most other hadrons since the velocity of the heavy constituents is small allowing a non-relativistic treatment of bound states. The NRQCD formalism is one of the most promising theoretical framework for the study of heavy quarkonium 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 NRQCD, the cross-section for direct production of a resonance H in a collision of particles A and B can be expressed in factorized form

$$E\frac{d^3\sigma^{ab\to cd}}{d^3p}(^{(2S+1)}L_J) = \sum_{a,b}\int dx_a\, dx_b$$
$$G_{a/A}(x_a,\mu_F^2)G_{b/B}(x_b,\mu_F^2)\frac{\hat{s}}{\pi}\frac{d\sigma}{d\hat{t}}$$
$$(ab \to^{(2S+1)} L_J c)\cdot\delta(\hat{s}+\hat{t}+\hat{u}-M^2)$$

where, $G_{a/A}(G_{b/B})$ is the parton distribution function (PDF) of the incoming parton $a(b)$ in the incident hadron $A(B)$, which depends on the momentum fraction $x_a(x_b)$ and the factorization scale μ_F. The short distance contribution $d\sigma/d\hat{t}$ can be calculated within the framework of perturbative QCD (pQCD). $(ab \to^{(2S+1)} L_J c)$ represents the probability of evolving a bound quarkonia state from a $Q\overline{Q}$ pair. These probabilities (LDMEs) should be estimated from the experimental measurements. In this work the production cross section of b$\overline{\text{b}}$ bound states is calculated in p+p collisions $\sqrt{s}$ = 7 TeV and measured data from CMS and ATLAS collaborations [3, 4] is used to constrain the LDMEs required for Υ(3S) production. The LDMEs are predicted to scale with a definite power of the relative velocity v of the heavy constituents inside $Q\bar{Q}$ bound 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 Υ(3S) can be written as the sum of these contributions,

$$\begin{aligned} d\sigma(\Upsilon(3S)) &= d\sigma(Q\overline{Q}([^3S_1]_1))\, M_L([^3S_1]_1) \\ &+ d\sigma(Q\overline{Q}[^1S_0]_8))\, M_L([^1S_0]_8) \\ &+ d\sigma(Q\overline{Q}([^3S_1]_8))\, M_L([^3S_1]_8) \\ &+ d\sigma(Q\overline{Q}([^3P_J]_8))\, M_L([^3P_0]_8) \end{aligned}$$

In our calculations, we used the expressions for the short distance cross-sections from Refs. [5, 6].

Results and discussion

Υ(3S) is the highest known bound state in the b$\overline{\text{b}}$ spectrum so it must not have any feed down contribution. The expressions and the values for the color-singlet LDMEs can be obtained by solving the non-relativistic wavefunctions [6]. The CO LDMEs can not be related to the non-relativistic wavefunctions of $b\bar{b}$ since it involves a higher Fock state and thus measured data [3, 4] is used to constrain them. Figure 1 shows the NRQCD calculations of production cross section of Υ(3S) in p+p collisions as a function of transverse momentum compared with the measured data in

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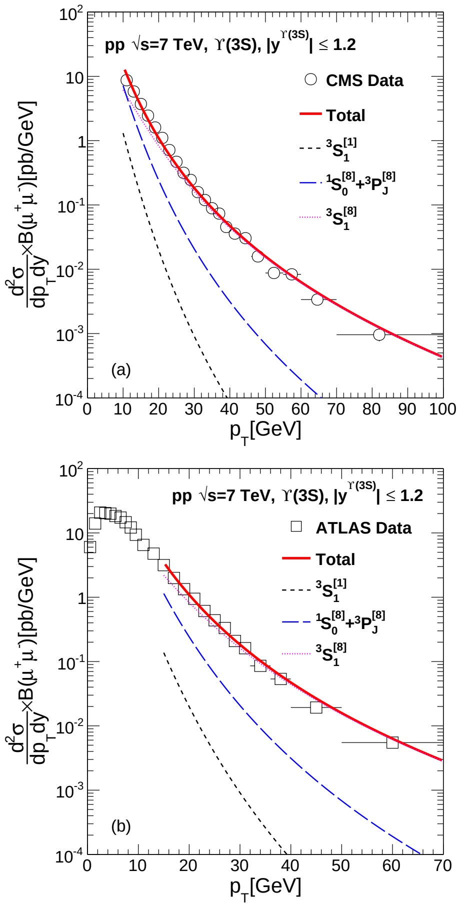

FIG. 1: The NRQCD calculations of production cross section of Υ(3S) in p+p collisions at $\sqrt{s} = 7$ TeV, as a function of transverse momentum compared with the measured data at CMS [3] and ATLAS [4] experiment. The LDMEs are obtained by a combined fit of the CMS and ATLAS data.

CMS [3] and ATLAS [3] detectors at LHC. The color-singlet contribution along with the calculated value and color-octet contributions fitted from data are given below for the Υ(3S) production.

$$\begin{aligned} M_L([^3S_1]_1) &= 4.3\,\text{GeV}^3 \\ M_L([^3S_1]_8) &= (0.0725 \pm 0.0013)\,\text{GeV}^3 \\ M_L([^1S_0]_8) &= (0.0126 \pm 0.0008)\,\text{GeV}^3 \\ &= M_L([^3P_0]_8)/5m_b^2\ \text{GeV}^3 \end{aligned}$$

The combined fitting of CMS and ATLAS data is done to extract common color octet LDMEs those explain both the datasets simultaneously. The χ^2/dof is 3.25 for the combined fitting. Our value of $M_L([^3S_1]_8)$ is compatible with the value obtained in the recent calculations [7] while the value of $M_L([^1S_0]_8)$ is larger than the value of Ref. [7]. We significantly improve the large ($\approx$ 300%) error present on the value of $M_L([^1S_0]_8)$ in Ref. [7], by using combined fitting and latest LHC data.

Summary

We have calculated the differential production cross-section of Υ(3S) meson as a function of transverse momentum. The data from LHC experiments are used to obtain the values of color octet LDMEs. We plan to present a rigorous study of production of all states of bottomonia at LHC energies using NRQCD. The reevaluation of all LDMEs required for bottomonia production is in progress using latest data from LHC.

References

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