Charmonium production in pp collisions at energies available at the CERN Large Hadron Collider

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The quarkonia production mechanism in $p-p$ collisions is qualitatively understood by the models based on the Quantum Chromodynamics(QCD), in particular, in the non-relativistic QCD (NRQCD) [1]. The quarkonia production in NRQCD is a two step process: First, the creation of the $Q\bar{Q}$ pair in a hard scattering at short distances which are process-dependent, is to be calculated perturbatively as an expansions in the strong coupling constant α_s. Note that $Q\bar{Q}$ states can be in the color-singlet(CS) [2] as well as in a color-octet(CO) [3] states. Second, the $Q\bar{Q}$ pair evolves into the quarkonium state with the probabilities that are given by the supposedly universal nonperturbative long-distance matrix elements (LDMEs) which have to be extracted from experiments. For CO states, this evolution process also involves the non-perturbative emission of soft gluons to form a CS states. The crucial feature of this formalism is that the complete structure of the $Q\bar{Q}$ Fock space, which is spanned by the states $n = {}^{2S+1}L_J^{[i]}$ with spin S, orbital angular momentum L, total angular momentum J, and color multiplicity $i = 1, 8$. The inclusive cross-section of charmoium include the prompt contribution (the sum of direct production and feeddown contributions from the decay of heavier charmonium states) and the B feeddown. The prompt contribution has been calculated using above mentioned NRQCD formalism and FONLL [4] formalism is dedicated to calculate the feeddown contributions from B meson to the J/ψ and $\psi(2S)$ productions.

According to the NRQCD factorization formalism, the cross section for direct production of a resonance H in a collision of particle A and B can be expressed as

$$d\sigma_{A+B\to H+X} = \sum_{i,j,n} \int dx_a dx_b G_{a/A}(x_a,\, \mu_F)$$
$$G_{b/B}(x_b,\, \mu_F) d\sigma(a+b \to Q\bar{Q}(n) + X) < \mathcal{O}^H(n) > \quad (1)$$

where $G_{a/A}(G_{b/B})$ is the partonic distribution function(PDF) of the incoming partons $a(b)$ in the incident hadron $A(B)$ which depends on the large light-cone momentum fraction $x_a(x_b)$ and the factorization scale μ_F. The short distance contribution $d\sigma(a+b \to Q\bar{Q}(n) + X)$ can be calculated within the framework of perturbative QCD(pQCD). On the other hand, $< \mathcal{O}^H(n) >$ are nonperturbative LDMEs and to be extracted from experiment.

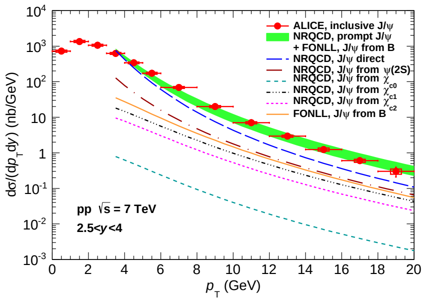

FIG. 1: Differential production cross-section vs. p_T for inclusive J/ψ compared with the ALICE data [6].

Results

The shaded band in Fig. 1 and 2 represent the predictions for the differential cross-sections of inclusive J/ψ and $\psi(2S)$ as a function of p_T for the rapidity interval 2.5<y<4 at $\sqrt{s}$ = 7 TeV, respectively, within the

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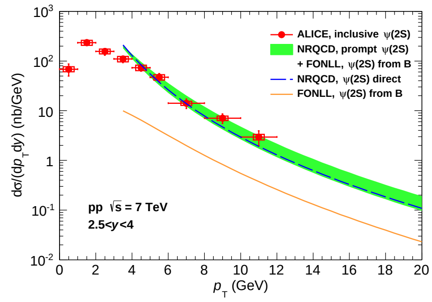

FIG. 2: Same as Fig. 1 but for inclusive $\psi(2S)$.

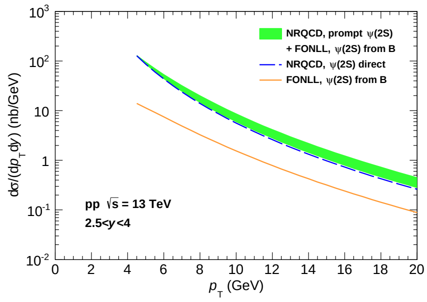

FIG. 5: Same as Fig. 4 but for inclusive $\psi(2S)$.

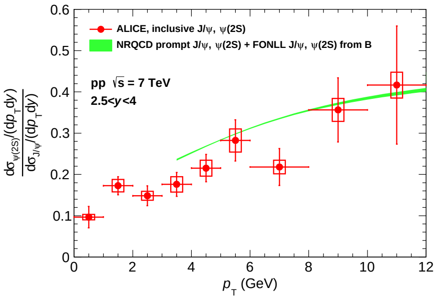

FIG. 3: Inclusive $\psi(2S)$ to J/ψ production cross-section ratio vs. p_T compared to the ALICE data [6].

NRQCD and FONLL framework [5]. The uncertainty limits on the calculated values correspond to the variation of the factorization scale μ_F. This uncertainty due to the factorization scale was estimated by performing the calculations for $\mu_F = \mu_R = \mu_0/2$ (upper bound) and $\mu_F = \mu_R = 2\mu_0$ (lower bound),

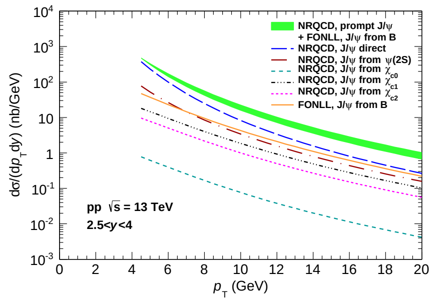

FIG. 4: Same as Fig. 1 but only with the theoretical prediction for the differential cross-sections for inclusive J/ψ at $\sqrt{s} = 13$ TeV [5].

here $\mu_0 = \sqrt{p_T^2 + 4m_c^2}$. These uncertainties were calculated for the direct production as well as for the feeddown contributions from $\psi(2S)$, χ_{c0}, χ_{c1} and χ_{c2}. However, in the figure, the feeddown contributions have been shown by lines which correspond to the calculated values for the central values of LDMEs and μ_F. The experimental data from ALICE [6] for the inclusive J/ψ and $\psi(2S)$ differential cross-sections has also been shown in this figures. The NRQCD calculations are unable to describe the experimental data for $p_T < 4$ GeV since in this domain the perturbative approximation fails. ALICE collaboration has also reported the $\psi(2S)$ to J/ψ cross-sections ratio at $\sqrt{s} = 7$ TeV [6]. These measured and calculated values are shown in Fig. 3. The experimental data shows a clear dip for the bin 6-8 GeV while the calculated values show a smooth increasing trend in the domain of $3.5 < p_T < 12$ GeV. The predicted cross-section for J/ψ and $\psi(2S)$ for $\sqrt{s} = 13$ TeV are shown in Figs. 4 and 5, respectively.

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