Charmonia production at LHC energies in NRQCD formalism

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In this work we calculate the production cross section of charmonia in p+p collisions at $\sqrt{s}$ = 7 TeV using Non Relativistic QCD (NRQCD) formalism. Under NRQCD the cross-section for direct production of a resonance H in a collision of particle A and B can be expressed in factorized form

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

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). $(ab \to^{(2S+1)} L_J c)$ are nonperturbative LDMEs and can be estimated by comparison with experimental measurements.

Charmonia Production in p+p collisions

The dominant processes in evaluating the differential yields of heavy quarkonia as a function of p_T are $g+q \to H+q$, $q+\bar{q} \to H+g$ and $g+g \to H+g$, where H refers to the heavy meson. The differential cross-section for the short distance contribution i.e. the heavy quark pair production from the reaction of the type $a + b \to c + d$ can be written as [1]

$$\frac{d\sigma^{ab\to cd}}{dp_T\, dy} = \int dx_a\, G_{a/A}(x_a,\, \mu_F^2)$$
$$G_{b/B}(x_b,\, \mu_F^2) \times 2p_T \qquad (1)$$
$$\frac{x_a\, x_b}{x_a - \frac{m_T}{\sqrt{s}}e^y}\frac{d\sigma}{d\hat{t}}(ab \to cd),$$

where, $\sqrt{s}$ being the total energy in the centre-of-mass and y is the rapidity of the $Q\bar{Q}$ pair. In our calculations we use CTEQ6M [2] for the parton distribution functions. The invariant differential cross-section is given by

$$\frac{d\sigma}{d\hat{t}} = \frac{|\mathcal{M}|^2}{16\pi\hat{s}^2}, \qquad (2)$$

where $\hat{s}$ and $\hat{t}$ are the parton level Mandelstam variables and $\mathcal{M}$ is the feynman amplitude for the process. The LDMEs are predicted to scale with a definite power of the relative velocity v of the heavy constituents inside $Q\bar{Q}$

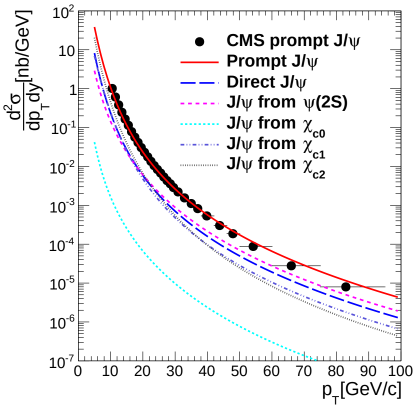

FIG. 1: Differential production cross-section of J/ψ as a function of p_T compared with the CMS measurement.

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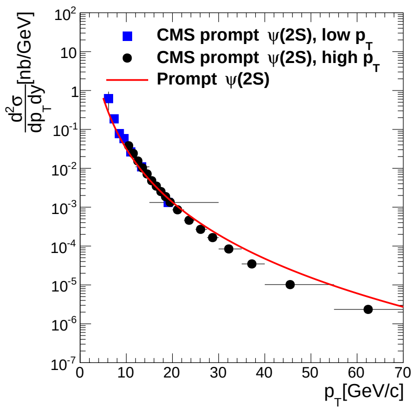

FIG. 2: Differential production cross-section of ψ(2S) as a function of p_T compared with the CMS measurement.

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 and ${}^1S_0^{[8]}$, ${}^3S_1^{[8]}$ and ${}^3P_J^{[8]}$ Color Octet states. In our calculations, we used the expressions for the short distance CS cross-sections given in Refs. [3–5] and the CO cross-sections given in Refs. [6, 7].

Results and discussion

For J/ψ production in p+p collisions, three sources need to be considered: direct J/ψ production, feed-down contributions to the J/ψ from the decay of heavier charmonium states, predominantly from $\psi(2S)$, χ_{c0}, χ_{c1} and χ_{c2} and J/ψ from weak decay of B hadron decays. The sum of the first two sources is called "prompt J/ψ" and the third source is called "*J/ψ from B*". Figure 1 shows the differential production cross-section of prompt J/ψ as a function of transeverse momentum (p_T) compared with the CMS measurements [8]. We have calculated differential production cross-sections for all the relevant resonances. These cross sections are then appropriately scaled with proper branching fractions and total cross section for prompt J/ψ is calculated and shown in Fig. 1. The ψ(2S) has largest contribution at high p_T while at low p_T contribution from χ_{c1} and χ_{c2} exceed the ψ(2S) contribution. After adding all the contributions, the p_T dependence of prompt J/ψ differential production cross-section are described reasonably well by our calculations. The $\psi(2S)$ has no significant feed-down contributions from higher mass states. We call this direct contribution as "prompt ψ(2S)" to be consistent with the J/ψ calculations. Figure 2 shows the differential production cross-section of prompt ψ(2S) as a function of p_T compared with the CMS measurements [8]. Here also our calculations qualitatively reproduced the mesaured cross section.

Summary

We have calculated the differential production cross-section of prompt J/ψ and prompt ψ(2S) as a function of transverse momentum. For the J/ψ meson all the relevent contributions from higher mass states are estimated. The ψ(2S) meson does not have significant contributions from higher mass states. The calculations for prompt J/ψ and prompt ψ(2S) are compared with the measured data at LHC. A fairly good agreement between measured data and calculations is observed in low p_T range. The reevaluation of LDME is in progress using latest data from LHC to achieve good description of data in the whole p_T range.

References

[1] J. F. Owens, Rev. Mod. Phys. **59**, 465 (1987).

[2] H. L. Lai *et al.* Phys. Rev. D **82**, 074024 (2010).

[3] R. Baier and R. Ruckl, Z. Phys. C **19**, 251 (1983).

[4] B. Humpert, Phys. Lett. B **184**, 105 (1987).

[5] R. Gastmans, W. Troost and T. T. Wu, Nucl. Phys. B **291**, 731 (1987).

[6] P. L. Cho and A. K. Leibovich, Phys. Rev. D **53**, 150 (1996).

[7] P. L. Cho and A. K. Leibovich, Phys. Rev. D **53**, 6203 (1996).

[8] V. Khachatryan *et al.* [CMS Collaboration], Phys. Rev. Lett. **114**, no. 19, 191802 (2015).