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Mini Review

J/Ψ (1S) and Ψ (2S) Production in p-p Collisions at E=5.44 TeV

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Abstract

I estimate the differential rapidity cross sections for J/Ψ and Ψ (2S) via pp (proton-proton) collisions at E=510 GeV. The J/Ψ is a standard charm quark and anti-charm quark, c and $\bar{c}$ while Ψ (2S) is a mixed hybrid c meson. For the Ψ (2S) I use the mixed heavy quark hybrid theory, with states approximately 50% standard and 50% hybrid charmonium.

Introduction

This new work on p-p collisions is based on the heavy quark state production formalism in Pb-Pb collisions at $\sqrt{s_{pp}}$ = p-p energy = 5.02 TeV [1].

I use the standard model the for J/Ψ state and the mixed hybrid theory [2] for Ψ (2S) the state.

In section 2 heavy quark hybrid states and mixed heavy quark hybrid states are reviewed. The charm quark c is needed with a mass [3] $m_c \simeq$ 1.27 GeV.

Also, the anti-quark $\bar{c}$ is needed. As discussed in section 2 the state J/Ψ (1S) is $|c\bar{c}(1S)>$ while state Ψ (2S) is a mixed hybrid c meson.

In section 3, Ψ production in p-p collisions is reviewed. My new work on heavy quark state production is based on the methods used in heavy quark state production in Cu-Cu and Au-Au collisions at $\sqrt{s_{pp}}$ = 200 GeV[4] which used the color octet model [5-7]. Prior to the article [?] Ψ (2S) and Ψ(3S) suppression in p-Pb collisions with E = $\sqrt{s_{pp}}$ = 5.02 TeV was estimated [8] and reviewed [9]. Also, the ALICE collaboration studied J/Ψ production via Xe-Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV [10].

Normal and mixed Charmonium States

The starting point of the method of QCD sum rules [11] is the correlator

$$\Pi^A(x) = \langle | T[J_A(x) J_A(0)] | \rangle , \quad (1)$$

With $|\rangle$ the vacuum state and the current $J_A(x)$ creates the states with quantum numbers A.

With c, $\bar{c}$ and g a charm quark, an anti-charm quark, and a gluon.

For the normal charmonium state J/Ψ (1S)

$$J_{c\bar{c}} = J_{c\bar{c}} , \quad (2)$$

while the mixed hybrid charmonium state Ψ (2S) J_c is

$$J_{c\bar{c}g} \simeq -f J_{c\bar{c}} + \sqrt{1-f^2} J_{c\bar{c}g} , \quad (3)$$

where f = 2.

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Note that $J_{c\bar{c}}$ creates a normal charmonium state J/Ψ (1S) and $J_{c\bar{c}g}$ creates a hybrid state Ψ (2S).

Differential rapidity cross sections for J/Ψ (1S) Production at E= 510 GeV

In the present work I use the theory described in detail in Ref [12] with applications to BNL-RHIC, LHC and Fermilab, based on the octet model [5-7] for pp production of heavy quark states; and used for studies of pp collisions for Upsilon production at forward rapidities [13] and for heavy quark production at 7 TeV [14] and 8 TeV [15]. This calculation is motivated by the report of preliminary data for J/Ψ, Ψ (2S) production via pp collisions at 510 GeV by the PHENIX Collaboration [16].

For helicity λ =0, the differential rapidity cross section is given by [12]

$$\frac{d\sigma_{pp\to\Phi(\lambda=0)}}{dy} = A_\Phi \frac{1}{x(y)} f_g(x(y),2m) f_g(a/x(y),2m)\frac{dx}{dy}, \quad (4)$$

with with a = $4m^2/s=3.46\times10^{-5}$, $s=E^2$, E = 510 $E=510$ GeV, m = 1.5 GeV (for charm quark) and [12] $A_\Phi = \frac{5\pi^3\alpha_s^2}{288m^3 s} < O_8^\Phi(^1S_0) >$ = 3.1×10^{-4} nb. X(y) and $\frac{dx}{dy}$ are given by (there was a typo in the numerator of $\frac{dx(y)}{dy}$, within Ref [12])

$$x(y) = 0.5\left[\frac{m}{510}(\exp y - \exp(-y)) + \sqrt{(\frac{m}{510}(\exp y - \exp(-y)))^2 + 4a}\right]$$

$$\frac{dx(y)}{dy} = \frac{m}{1020}(\exp y + \exp(-y))\left[1. + \frac{\frac{m}{510}(\exp y - \exp(-y))}{\sqrt{(\frac{m}{510}(\exp y - \exp(-y)))^2 + 4a}}\right]. \quad (5)$$

The gluonic distribution function $f_g(x)$, for $\sqrt{s}$ =E=510 GeV [12], is

$$f_g(x) \simeq 1334.21 - 67056.5x + 887962.0x^2 . \quad (6)$$

From Eqs(4,2,6) the differential rapidity cross sections for J/Ψ (1S) production via 510 GeV p-p collisions with the standard theory [3] are shown in the figure below.

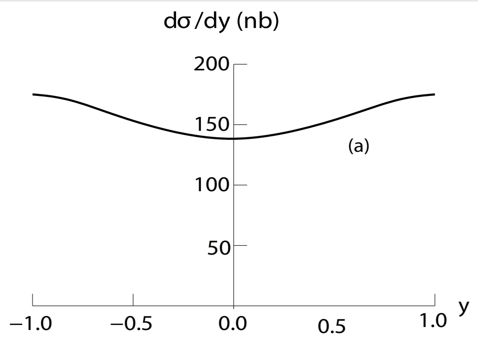

Figure 1: $d\sigma/dy$ for E=510 GeV p-p collisions with λ = 0 producing (a) J/Ψ (1S) with a standard $c\bar{c}$ model.

Conclusion

I have calculated the differential cross sections for pp collisions at 510 GeV for J/Ψ (1S) production with the standard $|c\bar{c}(1S)>$ model. As shown in the figure, $\frac{d\sigma_{pp\to J/\Psi(1S)}}{dy} \simeq$ 150 nb.

The cross-section for J/Ψ (1S) production in the standard model has been found in pp collision experiments at 200GeV [12].

References

1. Kisslinger LS, Das D. Heavy quark state production in Pb-Pb collisions at $\sqrt{s_{pp}}$ = 5.02TeV. JHEP; 2017; 09: 105 (2017)
2. Kisslinger LS. Mixed heavy quark hybrid mesons, decay puzzles, and RHIC. Phys Rev. D. 2009; 79; 114026.
3. Particle Physics Booklet. 2020.
4. Kisslinger LS, Liu MX, McGaughey P. Heavy-quark-state production A-A collisions at $\sqrt{s_{pp}}$ = 200 GeV. Phys Rev C 2014; 89: 024914.
5. Cho PL, Leibovich AK. Color-octet quarkonia production. Phys Rev D. 1996; 53: 150.
6. Braaten E, Chen YQ. Helicity decomposition for inclusive production. Phys Rev D. 1996; 54: 3216.
7. Braaten E, Fleming S. Color-Octet Fragmentation and the ψ' Surplus at the Fermilab Tevatron. Phys Rev Lett. 1995; 74: 3327.
8. Kisslinger LS. Ψ(2S), Υ(3S) Suppression in p-Pb, Pb-Pb Collisions and Mixed Hybrid Theory. Int J Theor Phys. 2016; 55: 1847-1853.
9. Kisslinger LS, Das D. Int J Mod Phys A. 2016; 13: 1630010.
10. Acharya S. Inclusive J/ψ production in Xe–Xe collisions at $\sqrt{s_{NN}}$ = 5.44TeV. Phys Lett B. 2018; 785: 419.
11. Shifman MA, Vainstein AI, Zakharov VI. QCD and resonance physics. theoretical foundations. Nucl Phys. B. 1979;147: 385.
12. Kisslinger LS, Liu MX, McGaughey P. Heavy-quark-state production in p-p collisions. Phys Rev D. 2011; 84: 114020.
13. Kisslinger LS, Das D. Upsilon production in pp collisions for Forward Rapidities at LHC. Mod Phys Lett A. 2013; 28: 1350067.
14. Kisslinger LS, Das D. Ψ and Υ Production In pp Collisions at 7.0 TeV. Mod Phys Lett A. 2013; 28: 1350120.
15. Kisslinger LS, Das D. Mod Phys Lett A. 2014; 29: 1450082.
16. Durham JM. PHENIX Collaboration. Science Direct. Nuc Phys A. 2014; 1.
17. Kisslinger LS. Mixed Heavy Quark Hybrid Mesons, Decay Puzzles, and RHIC. Pchys Rev. 2009, 79: 114026.

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