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J/ψ production in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV in the recombination model

R. Peng [a,b,*], C.B. Yang [a]

[a] *Institute of Particle Physics, Hua-Zhong Normal University, Wuhan 430079, People's Republic of China*
[b] *College of Science, Wuhan University of Science and Technology, Wuhan 430065, People's Republic of China*

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Abstract

We first determine c and $\bar{c}$ shower parton distributions in jets induced by light and charm hard partons in the framework of the recombination model from relevant fragmentation functions. The shower parton distributions can be used to calculate other fragmentation functions and study charmed hadron production in other collisions. When the distributions are applied to reproduce the J/ψ production in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV, energy loss effect is taken into account for J/ψ production due to its momentum loss in traversing the dense medium. We find that the contribution of thermal–shower parton recombination dominates over other mechanisms of hadronization in the region of $3.3 < p_T < 5.8$ GeV/c. The calculated J/ψ transverse momentum spectrum is in good agreement with the experimental data.

Keywords: Recombination model; Fragmentation function; Shower parton distribution; Charmed meson production

1. Introduction

An anomalous J/ψ suppression that clearly exceeds the one expected from nuclear absorption has been observed by the NA50 Collaboration in Pb + Pb collisions at the CERN-SPS energy [1]. Such a phenomenon was predicted by Matsui and Satz [2] as a consequence of the dissociation of J/ψ in the deconfined phase of quarks and gluons. So the suppression of charmonium state (J/ψ, χ_c, ψ') due to color screening analogous to Debye charge screening is recognized as

* Corresponding author at: Institute of Particle Physics, Hua-Zhong Normal University, Wuhan 430079, People's Republic of China.
E-mail address: pengru_1204@hotmail.com (R. Peng).

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an important tool to probe the possible phase transition from hadronic matter to quark–gluon plasma (QGP). Recently PHENIX Collaboration has measured J/ψ suppression in d + Au [3,4], Au + Au [5,6] and Cu + Cu [7] collisions at RHIC. Cold nuclear matter (CNM) effects such as nuclear absorption, gluon shadowing and nucleon energy loss [8] are expected to modify the J/ψ yield. But the CNM effects on J/ψ are evaluated only from J/ψ measurement in d + Au collisions at RHIC energy [3,4]. And the predictions of J/ψ production in Au + Au and Cu + Cu collisions are based on the assumption that J/ψ production is unaffected by QGP formation. The anomalous suppression can also be described as a result of final state interaction of the $c\bar{c}$ pairs with the dense medium produced in the collisions: comovers interaction. The centrality and the rapidity dependences of J/ψ suppression in Au + Au and Cu + Cu collisions have been presented in the comover model [9]. The nuclear modification factor R_{AA} and the transverse momentum dependence of J/ψ production have also been investigated in the framework of the statistical hadronization model [10], the transport model with hydrodynamic equations [11] and the previously constructed thermal rate-equation approach [12], respectively. In this paper we study J/ψ transverse momentum spectrum in Au + Au collisions at RHIC energy in the quark recombination model.

With the parametrization of the shower parton distributions (SPDs) [13], the recombination model has given good agreement with the experimental data of the hadron production at low and intermediate p_T [14], and successfully described the Cronin effect on pion production in d + Au collisions [15]. In Ref. [16], the model has been applied to calculate the production of strange particles at all p_T in central Au + Au collisions. Based on the good descriptions of the production of hadrons in the noncharm sector, now we extend the application of the recombination model to the charmed meson production in central Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

The determination of SPDs created by hard parton (u, d quarks and gluon) has been achieved by studying the fragmentation function (FF) in the frame work of the recombination model [13]. In this paper we use the same method to determine the SPDs initiated by hard partons of charm quark or gluon and apply them to reproduce J/ψ production in Au + Au collisions.

This work is organized as follows. We first recapitulate the notion of SPD in the recombination model in the next section. Then we calculate the J/ψ production in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV in Section 3. A brief summary is given in the final section.

2. Charm shower parton distribution in jets

The fragmentation function (FF) $D_i^H(x)$ which is interpreted as the probability for a parton i to fragment to a hadron H carrying away a fraction x of its momentum can be expressed as a recombination process from shower partons as [17]

$$xD(x) = \int_0^x \frac{dx_1}{x_1} \int_0^x \frac{dx_2}{x_2} \left\{ S_i^q(x_1), S_i^{\overline{q'}}(x_2) \right\} R(x_1, x_2, x), \tag{1}$$

where $R(x_1, x_2, x)$ is the recombination function (RF) for the formation of a meson at momentum fraction x composed of a quark q at x_1 and an antiquark $\overline{q'}$ at x_2 in the shower initiated by hard parton, and

$$\left\{ S_i^q(x_1), S_i^{\overline{q'}}(x_2) \right\} \equiv \frac{1}{2}\left[S_i^q(x_1) S_i^{\overline{q'}}\left(\frac{x_2}{1-x_1}\right) + S_i^q\left(\frac{x_1}{1-x_2}\right) S_i^{\overline{q'}}(x_2) \right] \tag{2}$$

reflecting the symmetrization of the leading parton momentum fraction. $S_i^q(x_1)$ denotes the distribution of shower parton q with momentum fraction x_1 created by hard parton i. Its parametrization has the form [13]

$$S_i^j(z) = Az^a(1-z)^b\big(1+cz^d\big) \tag{3}$$

with $i = c$, g and $j = c$, $\bar{c}$, $u(\bar{u})$ or $d(\bar{d})$ in this paper. Contributions to charm shower parton contents from other hard parton flavor can be neglected. Our prime task is to determine the parameters A, a, etc. of all kinds of SPDs S_i^j necessary in our later calculations with the known FFs and RFs.

Now we consider the RF related to the invariant constituent quark distribution in a meson M [17]. The RF for a meson is

$$R_M(x_1,x_2,x) = \frac{1}{B(a,b)}\left(\frac{x_1}{x}\right)^a\left(\frac{x_2}{x}\right)^b\delta\left(\frac{x_1}{x}+\frac{x_2}{x}-1\right) \tag{4}$$

with $B(a,b)$ standing for the beta function which is determined by the normalization $\int_0^1 dy_1 \times \int_0^{1-y_1} dy_2\, R_M(y_1,y_2)/(y_1y_2) = 1$ with $y_i = x_i/x$. From the analysis of Drell–Yan production data in pion-initiated process, it is shown that $a = b = 1$ for pion in Ref. [17]. And for D-meson, because of the unequal masses of constituent quarks, the ratio of the momenta can be proportional to their masses $a/b = \overline{x_1}/\overline{x_2} = m_d/m_c \simeq 1/5$ [18]. Consequently, we have

$$R_D(x_1,x_2,x) = \frac{5x_1x_2^5}{x^6}\delta\left(\frac{x_1}{x}+\frac{x_2}{x}-1\right). \tag{5}$$

But for J/ψ, $m_c = m_{\bar{c}} = 1.5$ GeV and $m_{J/\psi} = 3.097$ GeV, where $m_{J/\psi} \approx (m_c + m_{\bar{c}})$. The relationship between the masses implies that the interaction between c and $\bar{c}$ is very weak, so the momentum fractions for c and $\bar{c}$ in a J/ψ must be constants. Considering the fact that c and $\bar{c}$ are moving together with the same velocity as J/ψ, we write the RF of J/ψ as the following form

$$R_{J/\psi}(x_1,x_2,x) = \frac{x_1x_2}{x^2}\delta\left(\frac{x_1}{x}-\frac{1}{2}\right)\delta\left(\frac{x_2}{x}-\frac{1}{2}\right) = \frac{1}{4}\delta\left(\frac{x_1}{x}-\frac{1}{2}\right)\delta\left(\frac{x_2}{x}-\frac{1}{2}\right). \tag{6}$$

This RF is the limiting result when both a and b in Eq. (4) are infinities.

In order to obtain the SPDs related to the production of charmed hadron, we select four kinds of $D(x)$ functions: $D_g^{J/\psi}$ [19], D_c^{π} [20], $D_c^{D^0}$ [21] and $D_c^{J/\psi}$ [22] with starting scale $Q = 2m_c = 3$ GeV$/c$. From Eq. (1), charm parton fragmentations are characterized as:

$$xD_c^{\pi}(x) = \int_0^x \frac{dx_1}{x_1}\int_0^x \frac{dx_2}{x_2} S_c^l(x_1) S_c^l\left(\frac{x_2}{1-x_1}\right) R_\pi(x_1,x_2,x) \tag{7}$$

and

$$xD_c^{D^0}(x) = \int_0^x \frac{dx_1}{x_1}\int_0^x \frac{dx_2}{x_2}\big\{S_c^l(x_1), S_c^c(x_2)\big\} R_D(x_1,x_2,x). \tag{8}$$

By assuming SU(2) flavor symmetry $S_c^u = S_c^{\bar{u}} = S_c^d = S_c^{\bar{d}}$, we use l to denote light quarks u, $\bar{u}$, d and $\bar{d}$ in the equations above. First of all, we get S_c^l from Eq. (7). And then applying S_c^l to Eq. (8),

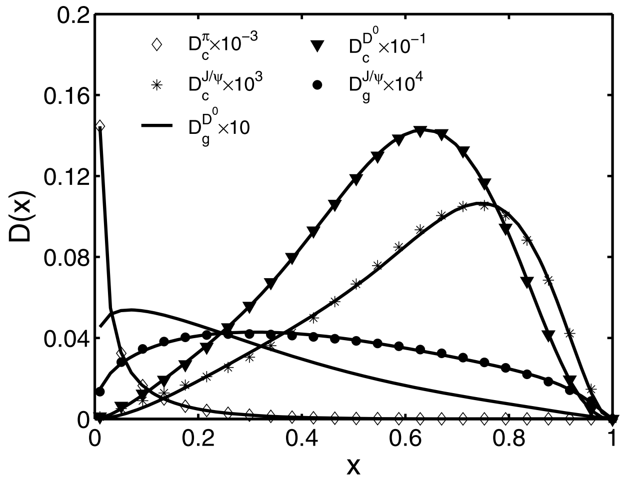

Fig. 1. Fragmentation functions of $D_g^{J/\psi}$ [19], D_c^{π} [20], $D_c^{D^0}$ [21] and $D_c^{J/\psi}$ [22] are shown in symbols, and the calculated results from the recombination model are shown by the solid curves. The curve without any symbol stands for the predicted result of $D_g^{D^0}$.

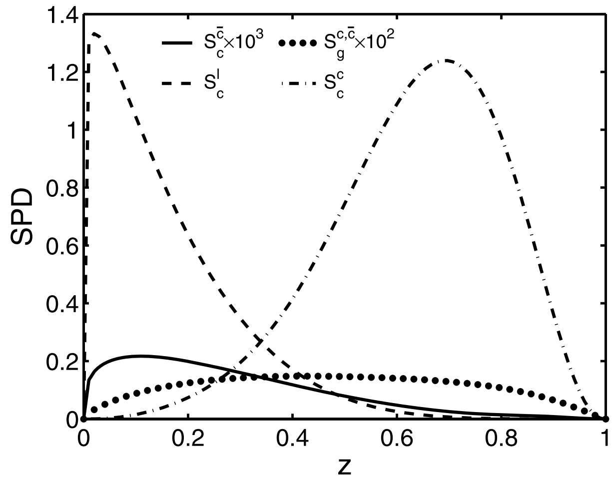

Fig. 2. Shower parton distributions determined from the recombination model, represented with the parameters given in Table 1.

we can obtain S_c^c. $S_g^{c,\bar{c}}$ ($S_g^c = S_g^{\bar{c}}$) and $S_c^{\bar{c}}$ can be determined in the same way if we replace D_c^{π} and $D_c^{D^0}$ with $D_g^{J/\psi}$ and $D_c^{J/\psi}$, respectively.

The FFs can be well reproduced in the recombination model with the parametrized SPDs. It is obvious that all the fits shown in Fig. 1 are excellent. The corresponding SPDs are shown in Fig. 2. The parameters for the SPDs are tabulated in Table 1. It is evident that the distribution of light quarks initiated from hard parton c is higher than that of c quark in the region of small momentum fraction $x < 0.35$, and lower when x is large. In other words, there are more light quarks than charm quarks at low momentum fraction. The distribution of c quark created in a

Table 1
Parameters for shower parton distributions.

	A	a	b	c	d
$S_g^{c,\bar{c}}$	5.020×10^{-3}	0.702	1.201	1.952	4.415
S_c^l	2.185	0.102	4.017	−0.879	1.066
S_c^c	6.483	2.526	2.375	22.819	3.233
$S_c^{\bar{c}}$	5.879×10^{-4}	0.315	2.577	23.505	16.078

c jet is much higher than that of $\bar{c}$ quark in almost the whole region and reaches its maximum at $x \approx 0.7$. This is basically because of two facts: (1) valence quark gives important contribution in the distribution, and (2) sea $c\bar{c}$ pair is hard to be produced considering the large mass of c quark. Compared with the SPDs obtained in Ref. [13], a gluon jet has a density of produced light or strange quarks higher than that of charm quarks.

From the above results, one can conclude that the charmed meson FF can also be described by the quark recombination model. The scale Q^2 dependence of the SPDs of light quarks in jets induced by light hard partons is given in Ref. [23], where one can obtain S_g^l with $Q = 2m_c = 3\ \text{GeV}/c$. With the known SPDs of $S_g^{c,\bar{c}}$ and S_g^l, $D_g^{D^0}$ can be calculated. The result is shown in Fig. 1 by the solid curve without any symbol.

3. J/ψ production in Au + Au collisions

In the recombination model [17], the inclusive distribution of the J/ψ production in Au + Au collisions can also be calculated. In this paper we substitute p for p_T to denote transverse momentum. The two components of parton sources that contribute to the joint parton distribution $F_{c\bar{c}}$ are thermal ($\mathcal{T}$) and shower ($\mathcal{S}$). The joint distribution can be expressed as the sum of three terms

$$F_{c\bar{c}}(p_1, p_2) = \mathcal{T}\mathcal{T} + \mathcal{T}\mathcal{S} + \mathcal{S}\mathcal{S}, \tag{9}$$

corresponding to different combinations from the two sources for c and $\bar{c}$ quarks. In this paper for the $\mathcal{S}\mathcal{S}$ term, we only take into account two shower partons arising from one jet because the recombination from two jets is much lower than others at RHIC [14]. So this term is exactly the same as from the fragmentation functions.

According to Ref. [24] which provides a theoretical description of the recombination process in a dense parton phase, the pure thermal J/ψ production ($\mathcal{T}\mathcal{T}$ contribution) can be calculated as

$$\frac{dN_{J/\psi}^{\mathcal{T}\mathcal{T}}}{d^2p} = C_{J/\psi} M_T \frac{\tau A_T}{(2\pi)^3} 2\gamma_c^2 I_0\left[\frac{p \sinh \eta_T}{T}\right] \int_0^1 dx \left|\phi_{J/\psi}(x)\right|^2 k_M(x, p), \tag{10}$$

where

$$k_M(x, p) = K_1\left[\frac{\cosh \eta_T}{T}\left(\sqrt{m_c^2 + x^2p^2} + \sqrt{m_{\bar{c}}^2 + (1-x)^2p^2}\right)\right]. \tag{11}$$

I_0 and K_1 in the equations above are modified Bessel functions. M_T is the transverse mass of J/ψ and $A_T = \rho_0^2\pi$ is the transverse area of the parton system with the radius $\rho_0 = 9$ fm [24]. It was assumed that hadronization occurs at $\tau = 5$ fm and the temperature $T = 175$ MeV in

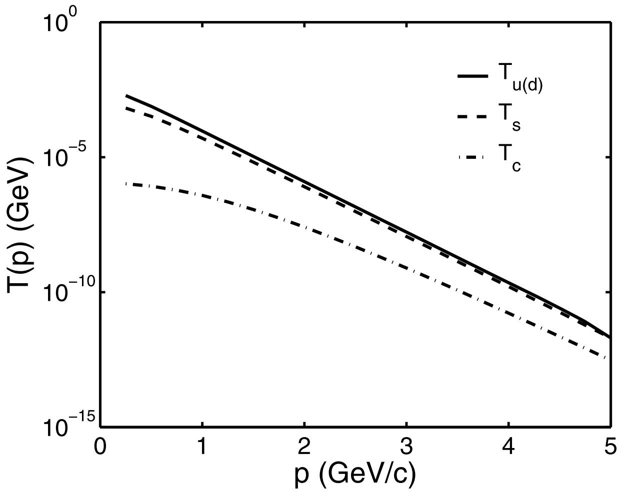

Fig. 3. The thermal parton distribution densities of $u(d)$, s and c.

the parton phase [24], which is consistent with predictions of the phase transition temperature at vanishing baryon chemical potential from lattice QCD [25]. The limiting case of extremely narrow wave function of J/ψ in the momentum space corresponds to a δ-shaped wave function $|\phi_{J/\psi}(x)|^2 = \delta(x - 1/2)$. The transverse flow rapidity η_T is defined by a velocity with $v_T = \tanh \eta_T$. The quark fugacity γ is related to the deviation of the evolving system from chemical equilibrium. The radial flow v_T and the c quark fugacity γ_c are the factors adjusted to fit the measured J/ψ transverse momentum spectrum in low p_T region. In principle every quark has 3 color and 2 spin degrees of freedom. So we use the meson degeneracy factor $C_{J/\psi} = (3 \times 2)^2$. The fitted results of v_T and γ_c are

$$v_T = 0.3c, \qquad \gamma_c = 0.260. \tag{12}$$

For thermal–shower recombination, the most important thing is to determine the distribution forms of $\mathcal{T}$ and $\mathcal{S}$. Again using the transverse momentum distribution of thermal partons given in Ref. [24], the thermal parton transverse momentum distribution density is

$$\mathcal{T}(p_1) = \left.\frac{dN^{th}}{dp_1^2\,dy}\right|_{y=0} \Big/ (\tau A_T). \tag{13}$$

From this definition one can see that $\mathcal{T}(p)$ has a dimension of GeV. The thermal parton distribution densities $\mathcal{T}(p)$ of $u(d)$, s and c are shown in Fig. 3 with the fugacities and the masses of the quarks used in Ref. [24]: $\gamma_u = \gamma_d = 1$, $\gamma_s = 0.8$ and $m_u = m_d = 0.26$ GeV, $m_s = 0.46$ GeV. Although the strange content in the medium is a little bit lower than that for u, d quarks, that for charm quarks is about an order of magnitude lower, as can be seen from Fig. 3.

In central Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV at mid-rapidity, the distribution of hard parton i with transverse momentum k just after hard scattering is [26,27]

$$f_i(k) = \left.\frac{dN_i^{\text{hard}}}{d^2k\,dy}\right|_{y=0}. \tag{14}$$

As can be seen from this expression, the spatial volume of the colliding system is included in $f_i(k)$. If we consider the loss of energy, after propagating through the medium with thickness L, the parton transverse momentum (q) distribution is changed from $f_i(k)$ to $F_i(q)$ [28]

$$F_i(q) = \frac{1}{\beta L} \int_q^{qe^{\beta L}} \frac{dk}{k} f_i(k) \tag{15}$$

with βL being the explicit dynamical medium factor. Using the SPDs calculated in Section 2, we can determine the distribution of shower parton j with transverse momentum p_1 in Au + Au collisions as following

$$\mathcal{S}(p_1) = \sum_i \int \frac{dq}{q} F_i(q) S_i^j(p_1/q). \tag{16}$$

With the same argument in Ref. [24], if we use for a species of partons $\omega(R, p)$ as the phase space distribution, the thermal parton distribution density defined as Eq. (13) is

$$\mathcal{T}(p_1) = \frac{g\gamma}{\tau A_T} \int_\Sigma d\sigma_R \frac{p_1^\mu u_{1\mu}(R)}{(2\pi)^3} \omega(R, p_1), \tag{17}$$

where $g = 6$ is counting the color and spin degeneracies of a quark, and $u_1(R)$ is the future oriented unit vector orthogonal to the hypersurface Σ defined by the hadronization volume. The thermal–shower term of the J/ψ production ($\mathcal{TS}$ contribution) can be calculated as [24]

$$\begin{aligned} \frac{dN_{J/\psi}^{\mathcal{TS}}}{d^2p} &= C_{J/\psi} \int_\Sigma d\sigma_R \frac{p^\mu u_\mu(R)}{(2\pi)^3} \int_0^1 dx \left|\phi_{J/\psi}(x)\right|^2 \\ &\quad \times \left[\omega_c(R, p_1)\mathcal{S}_{\bar{c}}(R, p_2) + \mathcal{S}_c(R, p_1)\omega_{\bar{c}}(R, p_2)\right] \\ &= \frac{C_{J/\psi}}{g\gamma_c} \left[\mathcal{T}_c(p/2)\mathcal{S}_{\bar{c}}(p/2) + \mathcal{S}_c(p/2)\mathcal{T}_{\bar{c}}(p/2)\right]. \end{aligned} \tag{18}$$

The denominator $g\gamma_c$ in Eq. (18) comes from the integral of Σ, because the factor has been included in $\mathcal{T}(p/2)$'s. In deriving the last line of Eq. (18), we have assumed that the shower partons are distributed uniformly in space volume, and the volume of the system is included in $\mathcal{S}(p/2)$'s.

Here, it is noticeable that $\mathcal{T}(p_1)$ is the parton transverse momentum distribution divided by the volume of the parton system $V = \tau A_T$, as exhibited in Eq. (13). $\mathcal{S}(p_1)$ denotes the shower parton distribution created by all the hard partons in the system. If we use $\omega(k)$ to denote the three-dimensional momentum space distribution, the number of hard partons in the system is

$$dN = V \cdot \frac{d^3k}{(2\pi)^3} \omega(k). \tag{19}$$

On the other hand the hard parton transverse momentum distribution is defined as

$$f_i(k) = E\frac{dN}{d^3k}, \tag{20}$$

where E is the energy of the hard parton. From the above two equations, one can get $\omega(k) \cdot V = f_i(k) \cdot (2\pi)^3/E$. Therefore, the shower distributions $\mathcal{S}_c$ and $\mathcal{S}_{\bar{c}}$ in Eq. (18), which correspond to

$\omega(k) \cdot V$ in Ref. [24], can be calculated from Eqs. (15) and (16) by using $f_i'(k) = f_i(k) \cdot (2\pi)^3/E$ in place of $f_i(k)$.

Since the shower–shower recombination term ($\mathcal{SS}$ contribution) is equivalent to the fragmentation functions, it has the simplest form [28]

$$\frac{dN^{\mathcal{SS}}_{J/\psi}}{p\,dp} = \frac{1}{p^0 p}\sum_i \int \frac{dq}{q} F_i'(q) \frac{p}{q} D_i^{J/\psi}\left(\frac{p}{q}\right), \tag{21}$$

where

$$F_i'(q) = \frac{1}{\beta L}\int_q^{qe^{\beta L}} dk\, k f_i(k). \tag{22}$$

The suppression factor quantified by βL in $F_i(q)$ and $F_i'(q)$ for gluon jet has been determined with $\beta L = 2.9$ by fitting the single-pion inclusive distribution [28]. $f_i(k)$ is the distribution for parton with momentum k at creation point. $F_i'(q)$ is the corresponding distribution after traversing a distance t in the medium with momentum $q = ke^{-\beta t}$. In Eq. (22) the lower limit of integration corresponds to $t = 0$, i.e., when the hard scattering occurs at the surface, while the upper limit corresponds to the case with the hard scattering point on the far side so that k is a factor of $e^{\beta L}$ larger than q. But for hard parton c, the traversing distance in QGP is much smaller than other light partons, since J/ψ is produced at the early stage in the collisions. So we choose $\beta L \to 0$ for $i = c$. In our calculations for J/ψ spectrum, we only consider g and c ($\bar{c}$) hard partons, considering the large abundance of gluon and valence dominance of c ($\bar{c}$) quarks. Contributions from other hard partons can be neglected.

What we should emphasize is that the FFs used in this paper are obtained with a fixed starting scale $2m_c$. Normally the virtuality Q^2 of hard partons increases with the transverse momentum p, which results in the increase of the FFs, so to the SPDs. Since the scale dependence of the charm parton FFs is not shown in Refs. [21] and [22], we cannot define the scale dependence of SPDs. In order to reflect the impact of the momentum on the scale, the results of $\mathcal{TS}$ and $\mathcal{SS}$ terms are multiplied by a factor of $1 - e^{-p/2}$ which suppresses the low p contributions.

In Fig. 4, we show the results of J/ψ production from our calculation. The sum of all contribution fits the experimental data well, except the last point. The recombination of thermal–thermal partons is larger than thermal–shower and shower–shower at $p_T < 3.3$ GeV/c, because in the low p_T region, the thermal parton distribution plays a major role. Thermal–shower dominates over shower–shower recombination at $2.6 < p_T < 5.8$ GeV/c and exceeds thermal–thermal when $p_T > 3.3$ GeV/c. This indicates that the recombination of thermal–shower partons is very important in the region of $3.3 < p_T < 5.8$ GeV/c. While according to the monotonously decreasing trends of $\mathcal{TS}$ and $\mathcal{SS}$ terms, $\mathcal{SS}$ exceeds $\mathcal{TS}$ to become the largest part at higher p_T, which is similar with the conclusion obtained in Ref. [14].

Since the critical temperature is estimated to be $T \simeq (160\text{–}190)$ MeV by lattice QCD Monte Carlo simulations [29], we present the effect of different T on the results. The fitted results with $T = 165$ MeV is a little changed with $\gamma_c = 0.337$ with the same v_T. The comparison of the total results of J/ψ production between $T = 175$ MeV and $T = 165$ MeV is shown in Fig. 5. There is a little difference in the J/ψ transverse momentum spectra for the two cases as shown. To fit the low p_T part of the experimental data, γ_c for the hadronization temperature $T = 165$ MeV is changed from 0.260 for $T = 175$ MeV to 0.337. Meanwhile the other parameter v_T is not

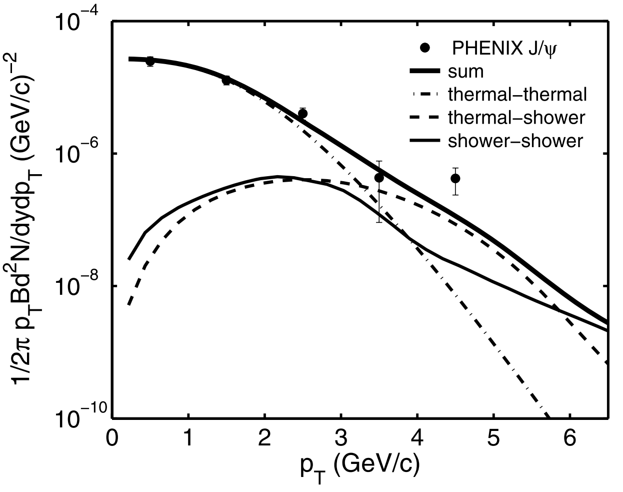

Fig. 4. The transverse momentum spectrum of J/ψ in central Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV (solid) for mid rapidity $|y| < 0.35$. The results are calculated with $T = 175$ MeV. The experimental data are from Ref. [6].

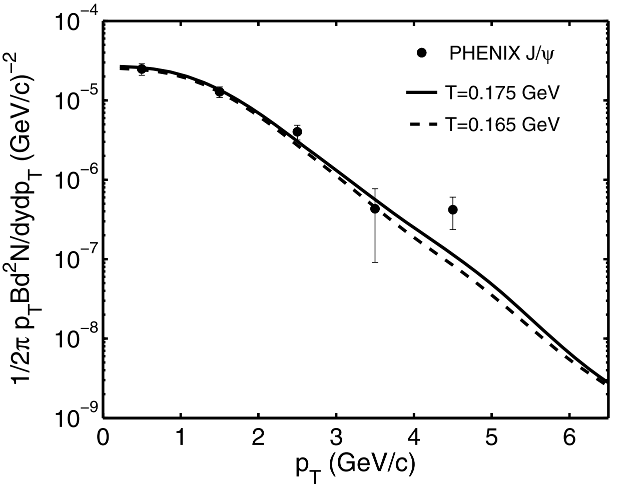

Fig. 5. The transverse momentum spectra of J/ψ in central Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV with $T = 175$ MeV (solid) and $T = 165$ MeV (dashed). The experimental data are from Ref. [6].

changed. From Fig. 5 one can see that the case with $T = 175$ MeV can fit the data a little bit better.

As can be seen from Eq. (10), the parameters τ, A_T and γ_c decide the overall normalization of $\mathcal{TT}$ term. If we change the value of τ or A_T, γ_c will be changed correspondingly to fit the data. In our fit, we have used the results from Ref. [24] on the values of τ and A_T in order to get γ_c. v_T is another parameter and its value is different for different mesons. With parameter T, v_T determines the shape of the $\mathcal{TT}$ contribution. In another work we have found that v_T is a constant for J/ψ transverse momentum spectra at different centralities.

4. Conclusion

We have obtained the shower parton distributions by describing the fragmentation process in the framework of recombination. The difference of this study from Ref. [13] is that the shower partons c and $\bar{c}$ discussed here are created by the hard partons of gluon or c quark. Because of the much larger mass of the charm quark, the possibility of the fragmentation from a light quark to a charmed meson is low. The recombination model cannot only reproduce some FFs in determining the SPDs but also be used to calculate other FFs without more input.

An important application of the SPDs is to reproduce the J/ψ spectrum in heavy ion collisions. In this work we have calculated the J/ψ transverse momentum spectrum in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV at mid-rapidity. The recombination of thermal–shower partons is vital due to its higher contribution than that of thermal–thermal and shower–shower in the region of $3.3 < p_T < 5.8$ GeV$/c$. And the term of $\mathcal{SS}$ which is determined completely by the fragmentation process plays a decisive role in higher momentum region. The energy loss effect of gluon is taken into account and this effect modifies the hard parton distribution after propagating through the dense medium. Another important factor is the scale dependence which may alter the FFs and then SPDs. The change caused by the scale can be remarkable as shown in Ref. [19]. In this paper, the effect of nuclear absorption or comovers interaction on J/ψ production and the feed-down from decays of resonances (χ_c, ψ') are not considered. Yet the fact that our results fit well with the experimental data suggests a success of applying the recombination model. The SPDs and the results of the J/ψ production will be improved with the more precise determination of the fragmentation functions.

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References

[1] L. Ramello, et al., NA50 Collaboration, Nucl. Phys. A 715 (2003) 243c.
[2] T. Matsui, H. Satz, Phys. Lett. B 178 (1986) 416.
[3] S.S. Adler, et al., PHENIX Collaboration, Phys. Rev. Lett. 96 (2006) 012304.
[4] A. Adare, et al., PHENIX Collaboration, Phys. Rev. C 77 (2008) 024912.
[5] S.S. Adler, et al., PHENIX Collaboration, Phys. Rev. C 69 (2004) 014901.
[6] A. Adare, et al., PHENIX Collaboration, Phys. Rev. Lett. 98 (2007) 232301.
[7] A. Adare, et al., PHENIX Collaboration, Phys. Rev. Lett. 101 (2008) 122301.
[8] R. Vogt, Phys. Rev. C 71 (2005) 054902;
R. Vogt, Acta Phys. Hung. A 25 (2006) 97.
[9] A. Capella, L. Bravina, E.G. Ferreiro, et al., Eur. Phys. J. C 58 (2008) 437.
[10] A. Andronic, P.B. Munzinger, K. Redlich, et al., Phys. Lett. B 652 (2007) 259.
[11] Y.P. Liu, Z. Qu, N. Xu, et al., Phys. Lett. B 678 (2009) 72.
[12] X.B. Zhao, R. Rapp, Eur. Phys. J. C 62 (2009) 109.
[13] R.C. Hwa, C.B. Yang, Phys. Rev. C 70 (2004) 024904.
[14] R.C. Hwa, C.B. Yang, Phys. Rev. C 66 (2002) 025205;
R.C. Hwa, C.B. Yang, Phys. Rev. C 67 (2003) 034902;
R.C. Hwa, C.B. Yang, Phys. Rev. C 70 (2004) 024905;
R.C. Hwa, C.B. Yang, Phys. Rev. C 70 (2004) 037901.

[15] R.C. Hwa, C.B. Yang, Phys. Rev. Lett. 93 (2002) 082302.
[16] R.C. Hwa, C.B. Yang, Phys. Rev. C 75 (2007) 054904.
[17] R.C. Hwa, Phys. Rev. D 22 (1980) 1593.
[18] R.C. Hwa, Phys. Rev. D 51 (1995) 85.
[19] E. Braaten, T.C. Yuan, Phys. Rev. Lett. 71 (1993) 1673.
[20] J. Binnewies, B.A. Kniehl, G. Kramer, Phys. Rev. D 52 (1995) 4947.
[21] B.A. Kniehl, G. Kramer, Phys. Rev. D 71 (2005) 094013.
[22] T.C. Yuan, Phys. Rev. D 50 (1994) 5664.
[23] Z.G. Tan, C.B. Yang, Chin. Phys. Lett. 23 (2006) 332.
[24] R.J. Fries, B. Müller, C. Nonaka, et al., Phys. Rev. C 68 (2003) 044902.
[25] F. Karsch, Nucl. Phys. A 698 (2002) 199.
[26] D.K. Srivastava, C. Gale, R.J. Fries, Phys. Rev. C 67 (2003) 034903.
[27] C.M. Ko, W. Liu, Nucl. Phys. A 783 (2007) 233c.
[28] R.C. Hwa, C.B. Yang, Phys. Rev. C 79 (2009) 044908.
[29] P. Petreczky, Nucl. Phys. A 785 (2007) 10;
P. Petreczky, Nucl. Phys. B (Proc. Suppl.) 140 (2005) 78.