Abstract

The cross sections of $\Upsilon$ absorption by $\pi$ and $\rho$ mesons are evaluated in a meson-exchange model. Including form factors with a cutoff parameter of 1 or 2 GeV, we find that due to the large threshold of these reactions the thermal average of their cross sections is only about 0.2 mb at a temperature of 150 MeV. Our results thus suggest that the absorption of directly produced $\Upsilon$ by hadronic comovers in high energy heavy ion collisions is unimportant.

PACS number(s): 25.75.-q, 13.75.Lb, 14.40.Gx, 14.40.Nd

I. INTRODUCTION

Recent experiments [1] at the CERN SPS have shown an anomalously large suppression of $J/\psi$ production in central Pb+Pb collisions. Following the original idea of Matsui and Satz [2] that $J/\psi$ would be dissociated in a quark-gluon plasma due to color screening, the observed $J/\psi$ suppression has been suggested as an evidence for the formation of the quark-gluon plasma in these collisions [3–5]. On the other hand, it has also been shown that $J/\psi$ absorption by comoving hadrons in the dense matter is important if the cross sections are taken to be a few mb [6–11]. Although these cross sections are much larger than those predicted in earlier theoretical studies based on either the perturbative QCD [12] or a simple hadronic Lagrangian [13], they are consistent with recent studies using the quark-exchange model [14,15] or a more general hadronic Lagrangian [16,17].

Since bottomonium states in a quark-gluon plasma are also sensitive to the color screening effect [18], the study of $\Upsilon$ suppression in high energy heavy ion collisions can be used as a signature for the quark-gluon plasma as well. Because of its larger binding energy than that of $J/\psi$, the critical energy density at which an $\Upsilon$ is dissociated in the quark-gluon plasma is also higher [19]. One thus expects to see the effects of the quark-gluon plasma on the production of $\Upsilon$ only in ultra-relativistic heavy ion collisions such as at the BNL RHIC and the CERN LHC. As in the case of $J/\psi$, one needs to understand the effects of $\Upsilon$ absorption in hadronic matter in order to use its suppression as a signal for the quark-gluon plasma in heavy ion collisions. In this paper, we shall study the $\Upsilon$ absorption cross sections by $\pi$ and $\rho$ mesons, which are the dominant hadrons in ultra-relativistic heavy ion collisions.

This paper is organized as follows. In Sec. [1], we introduce the hadronic Lagrangian and derive the relevant interaction Lagrangians between $\Upsilon$ and other hadrons. The cross sections for $\Upsilon$ absorption by $\pi$ and $\rho$ mesons are then evaluated in Sec. [11], and the numerical results are given in Sec. [14]. In Sec. [15], we show the relation between the cross sections for...
Υ absorption and those for $J/\psi$ absorption. Finally, discussions and a summary are given in Sec. VI.

II. THE HADRONIC LAGRANGIAN

We start from the following SU(5) symmetric free Lagrangian for pseudoscalar and vector mesons:

$$L_0 = \text{Tr} \left( \partial_\mu P^\dagger \partial^\mu P \right) - \frac{1}{2} \text{Tr} \left( F^{\dagger}_{\mu\nu} F^{\mu\nu} \right) ,$$  \hspace{1cm} (1)

where $F_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$, and $P$ and $V$ denote, respectively, the 5 × 5 pseudoscalar and vector meson matrices in SU(5):

$$P = \frac{1}{\sqrt{2}} \begin{pmatrix} \pi^- & \pi^0 & \rho^0 & \rho^+ & K^+ \\ K^- & \pi^0 & \rho^0 & \rho^+ & K^0 \\ D^0 & K^0 & \pi^+ & \rho^+ & D^+ \\ B^- & D^+ & \rho^+ & K^+ & B^0 \\ B^- & B^0 & K^+ & D^+ & B^0 \end{pmatrix} ,$$

$$V = \frac{1}{\sqrt{2}} \begin{pmatrix} \rho^- & \rho^0 & J/\psi & \rho^+ & \eta \\ K^- & \rho^0 & \eta & \rho^+ & \eta \\ D^0 & K^0 & \eta & \rho^+ & \eta \\ B^- & D^+ & \eta & K^+ & B^0 \\ B^- & B^0 & \eta & D^+ & B^0 \end{pmatrix} .$$

Introducing the minimal substitution as in Refs. [17,20],

$$\partial_\mu P \rightarrow D_\mu P = \partial_\mu P - \frac{ig}{2} [V_\mu, P] ,$$

$$F_{\mu\nu} \rightarrow \partial_\mu V_\nu - \partial_\nu V_\mu - \frac{ig}{2} [V_\mu, V_\nu] ,$$  \hspace{1cm} (3)

leads to the following interaction hadronic Lagrangian:

$$L = L_0 + ig \text{Tr} (\partial_\mu P [P, V_\mu]) - \frac{g^2}{4} \text{Tr} ( [P, V_\mu]^2 )$$

$$+ ig \text{Tr} (\partial^\nu V^\mu [V_\mu, V_\nu]) + \frac{g^2}{8} \text{Tr} ( [V_\mu, V_\nu]^2 ) .$$  \hspace{1cm} (5)

Since the SU(5) symmetry is explicitly broken by hadron masses, mass terms based on the experimentally determined values are added to the above hadronic Lagrangian.

Expanding the Lagrangian in Eq. (5) with the pseudoscalar meson and vector meson matrices shown in Eq. (2), we obtain the following interaction Lagrangians that are relevant for the absorption of Υ by π and ρ mesons:
\[ \mathcal{L}_{\pi BB^*} = ig_{\pi BB^*} \, B^{\mu*} \tau \cdot (B \partial_\mu \bar{\tau} - \partial_\mu B \bar{\tau}) + \text{H.c.}, \]
\[ \mathcal{L}_{\Upsilon BB} = ig_{\Upsilon BB} \, \Upsilon^\mu \left( B \partial_\mu B - \partial_\mu B B \right), \]
\[ \mathcal{L}_{\Upsilon B^* BB} = ig_{\Upsilon B^* BB} \left[ \Upsilon^\mu \left( \partial_\mu B^{\mu*} B^* - B^{\mu*} \partial_\mu B^* \right) + \left( \partial_\mu \Upsilon \bar{B}^\nu - \Upsilon^\nu \partial_\mu \bar{B}^\nu \right) B^{\mu*} \right. \]
\[ \left. + \bar{B}^{\mu*} \left( \Upsilon^\nu \partial_\mu B^* - \partial_\mu \Upsilon \bar{B}^* \right) \right], \]
\[ \mathcal{L}_{\pi \Upsilon BB^*} = -g_{\pi \Upsilon BB^*} \, \Upsilon^\mu \left( \bar{B}^{\mu*} \bar{\tau} B + \bar{\beta} \bar{\tau} B^* \right) \cdot \bar{\tau}, \]
\[ \mathcal{L}_{\rho BB} = ig_{\rho BB} \left( \bar{B} \bar{\tau} \partial_\mu B - \partial_\mu \bar{B} \bar{\tau} B \right) \cdot \bar{\rho}^\mu, \]
\[ \mathcal{L}_{\rho \Upsilon BB} = g_{\rho \Upsilon BB} \, \Upsilon^\mu \bar{B} \bar{\tau} B \cdot \bar{\rho}_\mu, \]
\[ \mathcal{L}_{\rho B^* BB} = ig_{\rho B^* BB} \left[ \left( \partial_\mu B^{\mu*} \bar{B}^* - B^{\mu*} \partial_\mu B^* \right) \cdot \bar{\rho}^\mu + \left( \bar{B}^{\mu*} \cdot \partial_\mu \bar{\rho}^\mu - \partial_\mu \bar{B}^{\mu*} \cdot \bar{\rho} \right) B^{\mu*} \right. \]
\[ \left. + \bar{B}^{\mu*} \left( \bar{\tau} \cdot \bar{\rho}^\mu B^* - \bar{\tau} \cdot \partial_\mu \bar{\rho}^\mu B^* \right) \right], \]
\[ \mathcal{L}_{\rho \Upsilon B^* B^*} = g_{\rho \Upsilon B^* B^*} \left( \Upsilon^\nu \bar{B}_\nu \bar{\tau} B^* + \Upsilon^\nu \bar{B}_\nu \bar{\tau} B^* - 2 \Upsilon \nu B^{\nu*} \bar{\tau} B^* \right) \cdot \bar{\rho}^\nu. \]

In the above, \( B \) and \( B^* \) denote, respectively, the pseudoscalar and vector bottom meson doublets, e.g., \( B = (B^+, B^0)^T \).

### III. \( \Upsilon \) Absorption Cross Sections

The above hadronic Lagrangians allow us to study the following processes for \( \Upsilon \) absorption by \( \pi \) and \( \rho \) mesons:

\[ \pi \Upsilon \rightarrow B^* B, \ \pi \Upsilon \rightarrow BB^*, \ \rho \Upsilon \rightarrow BB, \ \rho \Upsilon \rightarrow B^* B^*. \]  

(7)

Corresponding diagrams for these processes are shown in Fig. [I].

The total amplitude for the first process, \( \pi \Upsilon \rightarrow B^* B \), without isospin factors and before averaging (summing) over initial (final) spins, is given by

\[ \mathcal{M}_1 = \left( \sum_{i=a,b,c} \mathcal{M}_{1i}^{\nu \lambda} \right) \epsilon_{2\nu} \epsilon_{3\lambda} \equiv \mathcal{M}^{\nu \lambda}_{1} \epsilon_{2\nu} \epsilon_{3\lambda}, \]  

(8)

where the partial amplitudes for diagrams (1a), (1b), and (1c) are, respectively,

\[ \mathcal{M}_{1a}^{\nu \lambda} = -g_{\pi BB^*} \, g_{\Upsilon BB} \left( -2p_1 + p_3 \right)^\lambda \left( \frac{1}{u - m_B^2} \right) \left( 1 \right) \left( p_1 - p_3 + p_4 \right)^\nu, \]
\[ \mathcal{M}_{1b}^{\nu \lambda} = g_{\pi BB^*} \, g_{\Upsilon BB^*} \left( -p_1 - p_4 \right)^\nu \left( \frac{1}{u - m_{B^*}^2} \right) \left[ g_{\alpha \beta} - \frac{p_1 - p_4}{m_{B^*}^2} \right], \]
\[ \mathcal{M}_{1c}^{\nu \lambda} = -g_{\pi \Upsilon BB^*} \, g^{\nu \lambda}. \]  

(9)

In the above, \( p_j \) denotes the momentum of particle \( j \). We use the notation that particles 1 and 2 represent the initial-state mesons while particles 3 and 4 represent the final-state mesons on the left and right side of the diagrams shown in Fig. [I], respectively. The indices
\[
\begin{align*}
M_{2a}^{\mu\nu} &= -g_{\rho BB} g_{TB} \left( p_1 - 2p_3 \right)^\mu \left( p_1 - p_3 + p_4 \right)^\nu, \\
M_{2b}^{\mu\nu} &= -g_{\rho BB} g_{TB} \left( p_1 + 2p_4 \right)^\mu \left( u - m_{B^*}^2 \right) \left( -p_1 - p_3 - p_4 \right)^\nu, \\
M_{2c}^{\mu\nu} &= g_{\rho BB} g_{TB^*} \left[ g_{T_1 B}^{\mu\lambda} g_{T_2 B^*}^{\nu\omega} + g_{T_1 B}^{\mu\omega} g_{T_2 B^*}^{\nu\lambda} - 2 g_{T_1 B}^{\mu\nu} g_{T_2 B^*}^{\lambda\omega} \right].
\end{align*}
\]

Since the interaction Lagrangian in Eq. (5) is generated by the minimal substitution, which is equivalent to treating vector mesons as gauge particles, the total scattering amplitude for each process should satisfy the condition of current conservation in the limit of zero
vector meson masses, degenerate pseudoscalar meson masses, and SU(5) coupling constants, e.g., $M_1^{\mu \lambda} p_{3 \lambda} = 0$. One can easily check that the amplitudes given in Eqs. (3)-(5) all satisfy the current conservation condition.

After averaging (summing) over initial (final) spins and including isospin factors, the cross sections are

$$
\frac{d\sigma_1}{dt} = \frac{1}{96\pi s p_{i,cm}^2} M_1^{\mu \lambda} M_1^{\nu \lambda'} \left( g_{\nu \nu'} - \frac{p_{2 \nu} p_{2 \nu'}}{m_2^2} \right) \left( g_{\lambda \lambda'} - \frac{p_{3 \lambda} p_{3 \lambda'}}{m_3^2} \right),
$$

$$
\frac{d\sigma_2}{dt} = \frac{1}{288\pi s p_{i,cm}^2} M_2^{\mu \nu} M_2^{\nu \lambda'} \left( g_{\mu \mu'} - \frac{p_{1 \mu} p_{1 \mu'}}{m_1^2} \right) \left( g_{\nu \nu'} - \frac{p_{2 \nu} p_{2 \nu'}}{m_2^2} \right),
$$

$$
\frac{d\sigma_3}{dt} = \frac{1}{288\pi s p_{i,cm}^2} M_3^{\mu \lambda \nu} M_3^{\nu \lambda \nu'} \left( g_{\mu \mu'} - \frac{p_{1 \mu} p_{1 \mu'}}{m_1^2} \right) \left( g_{\nu \nu'} - \frac{p_{2 \nu} p_{2 \nu'}}{m_2^2} \right)
\times \left( g_{\lambda \lambda'} - \frac{p_{3 \lambda} p_{3 \lambda'}}{m_3^2} \right) \left( g_{\omega \omega'} - \frac{p_{4 \omega} p_{4 \omega'}}{m_4^2} \right),
$$

with $s = (p_1 + p_2)^2$, and $p_{i,cm}$ denoting the momentum of each initial-state meson in the center-of-mass frame.

With the exact SU(5) symmetry, the coupling constants in Eq. (3) can be related to the SU(5) universal coupling constant $g$ by the following relations:

$$
g_{\pi BB^*} = g_{\rho BB} = g_{\rho BB^*} = \frac{g}{4}, \ g_{TBB} = g_{TYB^*B^*} = \frac{5g}{4\sqrt{10}},
$$

$$
g_{\pi YYB^*} = g_{\rho YYB^*} = \frac{5g^2}{16\sqrt{10}}, \ g_{\rho YYB} = \frac{5g^2}{8\sqrt{10}}. \quad (15)
$$

These coupling constants can be further related to those involving light and charm mesons, i.e.,

$$
g_{\rho \pi \pi} = 2g_{\pi BB^*} = 2g_{\pi DD^*} = \sqrt{\frac{8}{3}} g_{TBB} = \sqrt{\frac{3}{2}} g_{\psi DD}.
$$

Values of the light and charm meson coupling constants are known [17], and they are $g_{\rho \pi \pi} = 6.1$, $g_{\pi DD^*} \approx 4.4$, and $g_{\psi DD} \approx 7.6$.

The three-point coupling constants for bottom mesons can also be determined phenomenologically. Using the vector meson dominance model as in Ref. [17] for charm mesons, we obtain

$$
g_{\rho BB} = g_{\rho BB^*} = \frac{e m_B^2}{2\gamma_\rho} = 2.52, \ g_{TBB} = g_{TYB^*B^*} = \frac{e m_B^2}{3\gamma_T} = 13.3. \quad (17)
$$

In the above, $\gamma_\rho$ is the photon-vector-meson mixing amplitude and can be determined from the vector meson partial decay width to $e^+e^-$. Also, the light-cone QCD sum rule [21] gives $g_{\pi BB^*} = 10.3$. We note that the above values for the coupling constants $g_{\pi BB^*}$, $g_{TBB}$, and $g_{TYB^*B^*}$ deviate appreciably from the SU(5) relation shown in Eq. (16). However, they agree with the predictions from the heavy quark symmetries [21, 23], i.e.,

$$
\frac{g_{\pi BB^*}}{g_{\pi DD^*}} \sim \frac{m_B}{m_D}, \ g_{TBB} \sim \frac{m_B}{m_D}, \ g_{\psi DD} \sim \sqrt{\frac{m_B}{m_D}}. \quad (18)
$$
Since the SU(5) is a broken symmetry, we shall use in the following calculations the phenomenological values for these coupling constants.

For the four-point coupling constants, there is no empirical information, and we thus use the SU(5) relations to determine their values in terms of the three-point coupling constants, i.e.,

\[ g_{\pi BB^*} = g_{BB^*\pi}, \quad g_{\rho BB^*} = 2 g_{BB^*\rho}, \quad g_{\rho BB^*} = g_{BB^*\rho} g_{BB^*}. \] (19)

To take into account the composite nature of hadrons, form factors need to be introduced at interaction vertices. Unfortunately, there are little empirical information on form factors involving bottom mesons or Υ states. We thus take the form factors to have the usual mono-pole form at the three-point \( t \) channel and \( u \) channel vertices, i.e.,

\[ f_3 = \frac{\Lambda^2}{\Lambda^2 + q^2}, \] (20)

where \( \Lambda \) is a cutoff parameter, and \( q^2 \) is the squared three momentum transfer in the center-of-mass frame, given by \( (p_1 - p_3)^2_{cm} \) and \( (p_1 - p_4)^2_{cm} \) for \( t \) and \( u \) channel processes, respectively. For simplicity, we use the same value for all cutoff parameters, and choose \( \Lambda \) as either 1 or 2 GeV to study the uncertainties due to form factors. We also assume that the form factor at four-point vertices has the following form:

\[ f_4 = \left( \frac{\Lambda^2}{\Lambda^2 + q^2} \right)^2, \] (21)

where \( q^2_{t,cm} + q^2_{u,cm} \) is the average value of the squared three momentum transfers in \( t \) and \( u \) channels.

**IV. NUMERICAL RESULTS**

In Fig. 2, we show the cross sections for Υ absorption by π and ρ mesons as a function of the center-of-mass energy \( \sqrt{s} \) of the initial-state mesons. The cross section for the πΥ process includes contributions from both \( \pi \Upsilon \rightarrow B^* \bar{B} \) and \( \pi \Upsilon \rightarrow BB^* \), which have the same cross sections. Since the centroid value of the ρ meson mass (770 MeV) is used in the calculation, all processes are endothermic. As a result, all cross sections have similar energy dependence near the threshold. Form factors are seen to strongly suppress the cross sections and thus cause large uncertainties in their values. With the cutoff parameter between 1 and 2 GeV, the values for \( \sigma_{\pi \Upsilon} \) and \( \sigma_{\rho \Upsilon} \) are roughly 8 mb and 1 mb, respectively.

The thermal average of these cross sections, given by

\[ \langle \sigma v \rangle = \frac{\int_{z_0}^\infty dz \left[ (\alpha_1 + \alpha_2)^2 - (\alpha_1 - \alpha_2)^2 \right] K_1(z) \sigma(s = z^2 T^2)}{4 \alpha_1^2 K_2(\alpha_1) \alpha_2^2 K_2(\alpha_2)}, \] (22)

with and without form factors are shown in Fig. 3. In the above, \( \alpha_i = m_i/T \) (\( i = 1 \) to 4), \( z_0 = \max(\alpha_1 + \alpha_2, \alpha_3 + \alpha_4) \), \( K_n \)’s are modified Bessel functions, and \( v \) is the relative velocity of initial-state particles in their collinear frame. We note that at a temperature of 150 MeV, for example, both \( \langle \sigma_{\pi \Upsilon} v \rangle \) and \( \langle \sigma_{\rho \Upsilon} v \rangle \) are only about 0.2 mb after including the form factors. This indicates that Υ absorption by hadronic comovers in the final state of high energy heavy ion collisions is not expected to be important.
FIG. 2. Cross sections of $\Upsilon$ absorption as a function of the center-of-mass energy of initial-state mesons with and without form factors. The cross section for the process $\rho\Upsilon \to B\bar{B}$ has been multiplied by a factor of 20.

V. COMPARISON WITH $J/\psi$ ABSORPTION BY HADRONS

It is interesting to compare our results for the $\Upsilon$ absorption with the $J/\psi$ absorption cross sections calculated from a similar Lagrangian [17]. Rescaling all momenta by the heavy meson mass $m_H$ and neglecting all light meson masses, the cross sections in Eqs. (12)-(14) without form factors can be factorized. Using the scaling relation of Eq. (18) for the coupling constants, we obtain

$$\sigma \left( \frac{\sqrt{s}}{m_H} \right) \propto \frac{g_1^2 g_2^2}{m_H^2} \propto m_H \text{ and } \frac{1}{m_H}$$

for the heavy quarkonium scattering cross sections with $\pi$ and $\rho$ mesons, respectively. From the numerical results shown in Fig. 2 and Ref. [17], we find that $\sigma_{\Upsilon}(\sqrt{s} = 14 \text{ GeV})/\sigma_{\psi}(\sqrt{s} = 5 \text{ GeV}) \sim 3$, 0.5, and 0.4 for the three processes shown in Fig. 1, respectively, and these ratios agree with the scaling relation of Eq. (23) within 50%.

As shown previously, the thermal averages of the $\Upsilon$ absorption cross sections by pion and rho mesons are both about 0.2 mb at $T = 150 \text{ MeV}$, which are roughly a factor of 5 to 10 smaller than the thermal averages of $\sigma_{\pi\psi}$ and $\sigma_{\rho\psi}$ at the same temperature and with the same form factors [17]. This is mainly due to the larger kinematic thresholds (i.e., $m_3 + m_4 - m_1 - m_2$) for the $\Upsilon$ absorption. With $m_\rho = 770 \text{ MeV}$, they are 1.01, 0.33, and 0.42 GeV, respectively, for the three processes shown in Fig. 1, compared to 0.64, −0.14, and 0.15 GeV for the corresponding $J/\psi$ absorption processes. The larger threshold for $\Upsilon$ absorption by hadrons not only prevents more light mesons from participating in the absorption process but also causes a larger reduction of the cross sections due to the form factors at interaction vertices.
FIG. 3. Thermal averages of the cross sections for Υ absorption as a function of temperature T with and without form factors.

VI. DISCUSSIONS AND SUMMARY

In our study, the hadronic Lagrangian shown in Eq. (5) is generated from the SU(5) flavor symmetry. The resulting PPV, VVV, PPVV and VVVV interaction Lagrangians are exactly the same as those in the chiral Lagrangian approach. However, the SU(5) flavor symmetry is badly broken by quark masses, especially by charm and bottom quark masses. Although in our study we have used the coupling constants determined from either the vector meson dominance model or the QCD sum rules, other symmetry-breaking effects are possible and need to be further studied. There are also large uncertainties on the values of the coupling constants. The coupling constant $g_{πBB^*}$ given by the QCD sum rules can differ by about a factor of 2, and the result from the lattice QCD studies is also inconclusive due to the large error bar. To include the symmetry breaking effects in hadronic models, an alternative approach based on both the chiral symmetry for light flavors and the heavy quark spin symmetry for charm and bottom flavors may be useful.

Since there is little experimental information available for form factors involving bottom mesons, significant uncertainties thus exist in results based on hadronic Lagrangians. To reduce these uncertainties, studies of B meson decays will be useful. For example, the form factor for B meson semileptonic decays $B \rightarrow πl\bar{ν}_l$, may be related to the form factor for the $πBB^*$ vertex. Recent studies based on QCD sum rules have shown that the $πBB^*$ and $πDD^*$ form factors as a function of the pion momentum roughly correspond to cutoff parameters between 1 and 2 GeV if they are fitted with the mono-pole form. Also, the form factor at the $ΥBB$ vertex is related to the form factors for decays such as $\bar{B} \rightarrow Dl\bar{ν}_l$.

We note that the absorption cross sections of the Υ by heavier mesons such as the kaon and charmed meson can be similarly calculated in our model. We have not included them...
in the present study as transport models have shown that the numbers of heavier mesons are much less than those of pions and rho mesons in high energy heavy ion collisions [32,33].

We have only considered the absorption of the $\Upsilon(1S)$ in hadronic matter. There are also heavier bound states of $b\bar{b}$, such as $\Upsilon(2S), \Upsilon(3S), \chi_{b0}(1P)$ and $\chi_{b1}(2P)$ ($i = 0, 1, 2$), which can decay into the $\Upsilon(1S)$. In $pp$ collisions, almost half of the final $\Upsilon(1S)$ yield is from the decay of these heavier particles [34]. To use $\Upsilon(1S)$ as a signal for the quark-gluon plasma in heavy ion collisions thus requires also information on the absorption cross sections of these particles by hadrons. Since they are less bound than $\Upsilon(1S)$, these heavy particles are more likely to be dissociated in both the partonic [19] and hadronic matter [34]. It will be useful to extend our meson-exchange model to include these heavier $b\bar{b}$ bound states in order to calculate their absorption cross sections.

In summary, we have studied the $\Upsilon$ absorption cross sections by $\pi$ and $\rho$ mesons using a hadronic Lagrangian based on the SU(5) flavor symmetry. Including form factors with a cutoff parameter of 1 or 2 GeV at the interaction vertices, we find that the values for $\sigma_{\pi\Upsilon}$ and $\sigma_{\rho\Upsilon}$ are about 8 mb and 1 mb, respectively. However, due to the large kinematic threshold, their thermal averages at a temperature of 150 MeV are both only about 0.2 mb. Our results thus suggest that the absorption of directly produced $\Upsilon$ by comoving hadrons is unlikely to be important in high energy heavy ion collisions.

**ACKNOWLEDGMENTS**

This work was supported in part by the National Science Foundation under Grant No. PHY-9870038, the Welch Foundation under Grant No. A-1358, and the Texas Advanced Research Program under Grant No. FY99-010366-0081.
REFERENCES

[1] M. Gonin et al., the NA50 Collaboration, Nucl. Phys. A610 (1996) 404c; M.C. Abreu
   et al., the NA50 Collaboration, Phys. Lett. B 450 (1999) 456.
[2] T. Matsui and H. Satz, Phys. Lett. B 178 (1986) 416.
[3] J.-P. Blaizot and J.-Y. Ollitrault, Phys. Rev. Lett. 77 (1996) 1703.
[4] C.-Y. Wong, Nucl. Phys. A630 (1998) 487.
[5] D. Kharzeev, M. Nardi and H. Satz, Phys. Lett. B 405 (1997) 14; D. Kharzeev, C.
   Lourenco, M. Nardi and H. Satz, Z. Phys. C 74 (1997) 307.
[6] W. Cassing and C.M. Ko, Phys. Lett. B 396 (1997) 39; W. Cassing and E.L.
   Bratkovskaya, Nucl. Phys. A623 (1997) 570.
[7] N. Armesto and A. Capella, Phys. Lett. B 430 (1998) 23.
[8] D.E. Kahana and S.H. Kahana, Phys. Rev. C 59 (1999) 1651.
[9] C. Gale, S. Jeon and J. Kapusta, Phys. Lett. B 459 (1999) 455.
[10] C. Spieles, R. Vogt, L. Gerland, S. A. Bass, M. Bleicher, H. Stöcker and W. Greiner,
    Phys. Rev. C 60 (1999) 054901.
[11] B.-H. Sa, A. Tai, H. Wang and F.-H. Liu, Phys. Rev. C 59 (1999) 2728.
[12] D. Kharzeev and H. Satz, Phys. Lett. B 334 (1994) 155.
[13] S.G. Matinyan and B. Müller, Phys. Rev. C 58 (1998) 2994.
[14] K. Martins, D. Blaschke and E. Quack, Phys. Rev. C 51 (1995) 2723.
[15] C.-Y. Wong, E.S. Swanson and T. Barnes, hep-ph/9912431; nucl-th/0002034.
    T. Barnes, E.S. Swanson and C.-Y. Wong, nucl-th/0006012.
[16] K. Haglin, Phys. Rev. C 61 (2000) 031902.
[17] Z. Lin and C.M. Ko, Phys. Rev. C 62 (2000) 034903.
[18] For recent reviews, see, e.g., R. Vogt, Phys. Rept. 310 (1999) 197; H. Satz, Rept. Prog.
    Phys. 63 (2000) 1511.
[19] F. Karsch, M. T. Mehr and H. Satz, Z. Phys. C 37 (1988) 617.
[20] Z. Lin and C.M. Ko, Phys. Rev. C 61 (1999) 024904; nucl-th/0006086.
[21] V.M. Belyaev, V.M. Braun, A. Khodjamirian and R. Ruckl, Phys. Rev. D 51 (1995)
    6177. Note that our coupling constants are a factor of 2\sqrt{2} smaller due to the difference
    in definitions.
[22] M.B. Wise, Phys. Rev. D 45 (1992) 2188; G. Burdman and J.F. Donoghue, Phys. Lett.
    B 280 (1992) 287.
[23] B. Grinstein and P.F. Mende, Phys. Lett. B 299 (1993) 127; E. de Rafael and J. Taron,
    Phys. Rev. D 50 (1994) 373.
[24] C. Song and V. Koch, Phys. Rev. C 55 (1997) 3026.
[25] P. Colangelo, G. Nardulli, A. Deandrea, N. Di Bartolomeo, R. Gatto and F. Feruglio,
    Phys. Lett. B 339 (1994) 151; H.G. Dosch and S. Narison, Phys. Lett. B 368 (1996)
    163; P. Colangelo and F. De Fazio, Eur. Phys. J. C 4 (1998) 503; A. Khodjamirian, R.
    Ruckl, S. Weinzierl and O. Yakovlev, Phys. Lett. B 457 (1999) 245.
[26] G.M. de Divitiis et al., UKQCD Collaboration, JHEP 9810 (1998) 010.
[27] M.B. Wise, Phys. Rev. D 45 (1992) 2188.
[28] G. Burdman, Z. Ligeti, M. Neubert and Y. Nir, Phys. Rev. D 49 (1994) 2331.
[29] F.S. Navarra, M. Nielsen, M.E. Bracco, M. Chiapparini and C.L. Schat, hep-ph/0005026.
[30] E. de Rafael and J. Taron, Phys. Lett. B 282 (1992) 215.
[31] S. Narison, Phys. Lett. B 325 (1994) 197.
[32] S.A. Bass, A. Dumitru, M. Bleicher, L. Bravina, E. Zabrodin, H. Stoecker, and W. Greiner, Phys. Rev. C 60 (1999) 021902.
[33] B. Zhang, C.M. Ko, B.A. Li, and Z. Lin, Phys. Rev. C 61 (2000) 067901.
[34] J.F. Gunion and R. Vogt, Nucl. Phys. B492 (1997) 301.