Different Nuclear Dependence of $J/\psi$ and $\psi'$ Production in p-A and A-p Collisions

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Abstract

While presently available p-A data observe that the nuclear dependence of $J/\psi$ and $\psi'$ production is the same within errors, we show that different nuclear dependence of $J/\psi$ and $\psi'$ production in the kinematic region uncovered by the present p-A data can be predicted based on two different nuclear absorption scenarios. It is found that the predicted production ratio $\sigma(\psi')/\sigma(J/\psi)$ at positive $x_F$ in A-p collisions is mainly determined by nuclear absorption, and hence allows direct experimental test of nuclear absorption scenarios.

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Quarkonium production in experiments with a proton-beam incident on a nucleus target, i.e. p-A collisions, has attracted much attention in recent years in connection with J/ψ suppressions in high energy heavy-ion collisions \[\text{[1-4]}\]. Actually it is a good place to check the hadronic absorption models which attribute the observed J/ψ suppressions in nucleus-nucleus collisions to the absorption of J/ψ through its interactions with hadronic environment instead of the formation of quark-gluon plasma (QGP). In particular, the experimental observations \[\text{[5,6]}\] that the J/ψ and ψ′ production has the same nuclear dependence in p-A collisions put a strict constraint on various absorption models. However, it has been realized that all present experiments for the production of J/ψ and ψ′ in p-A collisions studied only J/ψ or ψ′ which is fast in the lab system or has positive Feynman \(x_\text{F}\). In fact, in the kinematic region not yet probed by present p-A experiments, i.e. the negative \(x_\text{F}\) region, different nuclear dependence of J/ψ and ψ′ production can be predicted based on different scenarios of absorption by target nucleons, which will be shown in this work. One of these scenarios, the “traditional” nuclear absorption model (we shall refer to it as Scenario-I throughout this work), has been established in the literature \[\text{[7-10]}\] to account for the effects of absorption by nucleons in the following way: while the \(c\bar{c}\) pair (pre-meson), produced as a colour singlet and of small spatial size, is expanding gradually to its bound state size, it can be dissociated by nucleons through an interaction cross section depending on the size of the \(c\bar{c}\) pair. Very recently another scenario (Scenario-II) \[\text{[11]}\], stemming from the most recent theoretical progress made in hadronic production of quarkonium states, has been proposed to explain the observed charmonium suppression in hadron-nucleus and nucleus-nucleus collisions. This scenario considers charmonium production through the intermediate next-to-leading Fock space state consisting of a colour octet \(c\bar{c}\) pair and a soft gluon. The interaction between this composite state and nucleons can lead to charmonium suppression. In this work we shall show how these two different absorption scenarios could accommodate present p-A data and yet predict different nuclear dependence of J/ψ and ψ′ production in p-A collisions at negative \(x_\text{F}\).

At negative \(x_\text{F}\) in p-A collisions the mechanisms of charmonium production such as
nuclear shadowing [12–14] and intrinsic charm [15,10] are expected to be unimportant and will be neglected in our work. Initial state energy loss effects [16] may lead to an increase of charmonium production in the negative $x_F$ region, which gives an opposite trend to the experimental data. Furthermore, the usual EMC effects [17] can be important at negative $x_F$ [18]. The initial state energy loss and EMC effects are not included in our study and their effects will be discussed later. Our previous work [19] showed that $x_F$-dependent comover contributions, as well as the nuclear absorptions, are essential for a comparison between theories and experimental data at small $x_F$. We shall include only the effects of absorption by target nucleons and comovers in our study of $J/\psi$ and $\psi'$ production in p-A collisions at negative $x_F$. In fact, recent results on open charm production near $x_F=0$ [20] suggested that absorptions may be the dominant cause of the charmonium suppression in p-A collisions at negative $x_F$.

We shall show in this work that although the individual $J/\psi$ and $\psi'$ production at negative $x_F$ in p-A collisions predicted by the two different absorption scenarios may depend on the choice of parameters in comover contributions, the ratio of the two production cross sections $\sigma(J/\psi)/\sigma(\psi')$ is insensitive to comover contributions, and therefore the prediction of the ratio may allow an experimental test of nuclear absorption scenarios.

However, a study of charmonium production at negative $x_F$ (corresponding to the case of charmonium moving slow in the rest frame of target nucleus) is essentially impossible in an experiment of proton-beam incident on a nucleus target (p-A collisions). An alternative is the experiment of a heavy ion beam incident on a hydrogen or deuterium target [18,21], which we shall call A-p collisions. In A-p collisions the produced charmonia are moving fast in the lab system and thus the relevant measurements are more readily. In this work we have also calculated and compared the predictions of the mentioned two absorption scenarios for $J/\psi$ and $\psi'$ production in A-p collisions at CERN-SPS energy.

In Scenario-I for p-A collisions the produced charmonium states ($J/\psi$ or $\psi'$) or $c\bar{c}$ pairs (pre-mesons) can been dissociated by nucleons in the target nucleus into open-charm pairs ($D\bar{D}$), which leads to suppressions of charmonium production. However, the formation of
charmone immun bound state requires finite proper time, and this formation time will suffer a Lorentz delay in the lab system. In the kinematic region reached by present experiments, the produced $c\bar{c}$ pair is moving fast in the lab system and may have been outside the target nucleus before it forms a physical charmone bound state due to the Lorentz delay of the formation time in the lab system. Therefore, present experimental data show that the $J/\psi$ and $\psi'$ productions have the same nuclear dependence in p-A collisions, although the radii of the $J/\psi$ and $\psi'$ bound states differ by almost a factor of two in potential models [22].

According to this picture, those $c\bar{c}$ pairs which are slow in the lab system will have enough time to form the charmone bound states ($J/\psi$ or $\psi'$, etc.) inside the target nucleus, and thus the interaction of fully formed bound states $J/\psi$ and $\psi'$ with the surrounding target nucleons may lead to different nuclear dependence for $J/\psi$ and $\psi'$ production through the nuclear absorption depending on the final-state size, as we shall see below by explicit calculations.

Including only the effects of absorption by nucleons and comovers, the $x_F$-dependent cross section for quarkonium production in p-A collisions is

$$\frac{d\sigma^{pA}_{x_F}}{dx_F} = A \frac{d\sigma^{pp}_{x_F}}{dx_F} \int d^2 b \left\{ \int_{-\infty}^{+\infty} dz' \rho_{A}(b, z') e^{\exp \left\{ -\int_{-\infty}^{+\infty} dz' \rho_{A}(b, z') \sigma_{abs}(z' - z) \right\}} \frac{1}{\tau_f} \tau_{f(\tau,b)} \right\}, \quad (1)$$

where $\sigma^{pp}_{x_F}$ is the bare nucleon-nucleon cross section, $b$ the impact parameter and $\rho_{A}(b, z)$ the nuclear density.

The second exponential factor in Eq. (1) represents the comover contributions, where $\sigma_{co}$ is the $(c\bar{c})$-comover absorption cross section, $\tau_0$ is the formation time of comovers, $\tau_f$ is the effective proper time over which the comovers can interact with $c\bar{c}$ pair, $v_{re}$ is the relative velocity of $c\bar{c}$ with the comovers, and $n(\tau, b)$ is the density of comovers at the proper time $\tau$ and impact parameter $b$. In our calculations we have introduced the $x_F$ dependence of comover contributions through $n(\tau, b)$ as we did in Ref. [19], where $n(\tau, b)$ is related to the $x_F$-dependent comover distribution that is derived from the rapidity distribution of comovers. We fix $\tau_f = r_0/c_s$ with $r_0 \simeq 1.2$ fm and $c_s \simeq 1/\sqrt{3}$, $v_{re} \simeq 0.6$ [10]. We shall vary
the values of $\tau_0$ and $\sigma_{eo}$ to show the influence of comover contributions on the charmonium production at negative $x_F$.

The first exponential in Eq. (1) is the survival probability of the $c\bar{c}$ pair after its interaction with target nucleons. In the context of Scenario-I the nuclear absorption cross section is assumed to depend on the spatial separation of the $c\bar{c}$ pair, so that

$$
\sigma_{abs}(z' - z) = \begin{cases} 
\sigma_{RN}(\tau/\tau_R)^k & \text{if } \tau < \tau_R, \\
\sigma_{RN} & \text{otherwise},
\end{cases}
$$

where in general $k \geq 0$ and we shall take $k=2$ in our calculations. Here $R$ stands for charmonium bound states $J/\psi$ or $\psi'$. The formation time of $\psi'$ is taken as $\tau_{\psi'} \simeq 1.5$ fm [28], and the effective formation time of $J/\psi$ bound state is estimated to be $\tau_{\psi} \simeq 1.2$ fm, taking into account the fact that about 70% of the observed $J/\psi$ are directly produced and the remaining 30% come from the decay of $\chi_c$ [24]. We shall take the nuclear absorption cross sections for $J/\psi$ and $\psi'$ as $\sigma_{\psi N}=4$ mb from geometric considerations and $\sigma_{\psi' N} = \sigma_{\psi N}(r_{\psi'}/r_{\psi})^2 \simeq 3.7\sigma_{\psi N}$ [25][24].

The proper time $\tau$ in Eq. (2) is related to the distance traveled by the $c\bar{c}$ pair through $\tau = (z' - z)/\gamma v$, $v$ is the velocity of the $c\bar{c}$ pair in the rest frame of target nucleus, and $\gamma = (1 - v^2)^{-1/2}$. We can relate the velocity of the $c\bar{c}$ pair in the rest frame of target nucleus to the Feynman $x_F$ by

$$
\gamma v = \frac{P}{M} = \gamma_{cm}(P_L^* + \beta_{cm}\sqrt{(P_L^*)^2 + M^2}),
$$

where $P_L^* = x_F(P_L^*)_{max}$ is the longitudinal momentum of the $c\bar{c}$ pair in the center-of-mass system and its maximum is

$$
(P_L^*)_{max} = \sqrt{[s - (M + 2m_p)^2][s - (M - 2m_p)^2]/2\sqrt{s}}.
$$

Here $M$ is the mass of the $c\bar{c}$ system, $m_p$ the mass of a proton, and $s$ the center-of-mass energy squared. The transformation from the rest frame of the target nucleus to the center-of-mass system is given by $\gamma_{cm} = (E_b + m_p)/\sqrt{s}$, and $\beta_{cm} = P_b/(E_b + m_p)$, where $E_b$ and $P_b$ are the energy and momentum of the projectile beam in the lab system. One can see from
Eq. (3) that a $J/\psi$ produced at negative $x_F$ corresponds to a slow $J/\psi$ in the rest frame of the target nucleus.

We have calculated the $x_F$ dependence of $\alpha$ for $J/\psi$ and $\psi'$ production at negative $x_F$ in Fermilab E772/E789 p-A collisions in the parametrization,

$$\frac{d\sigma_{pA}^{\beta}}{dx_F} = \frac{d\sigma_{pp}^{\beta}}{dx_F} A^{\alpha(x_F)}. \tag{5}$$

The results are shown in Fig. 1 by the upper two curves, with the solid curve for $J/\psi$ production and the dashed for $\psi'$ production, parameters in comover contributions taken as $\sigma_{co}=4$ mb, $\tau_0=0.8$ fm. Also shown are the Fermilab E789 data on the $J/\psi$ production at $x_F \lesssim 0$ [26]. The curves are a little above the E789 data because for $J/\psi$ production the nuclear shadowing effect can contribute somehow at $x_F \simeq 0$ [19]. It can be seen that Scenario-I actually gives the same nuclear dependence for $J/\psi$ and $\psi'$ production in p-A collisions at $x_F \gtrsim 0$, as E772/E789 experiments have observed. However, different nuclear dependence for $J/\psi$ and $\psi'$ production appears at $x_F \lesssim -0.2$, which is beyond the E772/E789 data.

Note that the rise of $\alpha_{J/\psi}$ (solid curve in Fig. 1) at negative $x_F$ is due to the $x_F$-dependent comover contributions in Eq. (1).

As we discussed above, in order to confront experiments we have calculated the production of $J/\psi$ and $\psi'$ in A-p collisions at CERN-SPS energy $\sqrt{s}=17.4$ GeV. As a matter of fact, the production at positive $x_F$ in A-p collisions corresponds to the production at negative $x_F$ in p-A collisions. In Fig. 2 we show the results of $J/\psi$ and $\psi'$ production in A-p collisions at CERN-SPS energy for two sets of parameters $\sigma_{co}$ and $\tau_0$ in comover contributions: the upper two curves with $\sigma_{co}=2$ mb and $\tau_0=1.0$ fm (dot-dashed curve for $\alpha_{J/\psi}$ and dotted curve for $\alpha_{\psi'}$); the lower two curves with $\sigma_{co}=4$ mb and $\tau_0=0.8$ fm (solid curve for $\alpha_{J/\psi}$ and dashed curve for $\alpha_{\psi'}$). One sees that comover contributions are essential for charmonium production at positive $x_F$ in A-p collisions.

In order to reduce the uncertainties caused by the comover contributions, we have studied the production ratio $R_{\psi'/\psi} \equiv \sigma(\psi')/f\sigma(J/\psi)$ in A-p collisions at CERN-SPS energy, keeping in mind that comover contributions depends weakly on the type of produced charmonium.
Here \( f \simeq 0.14 \) is the experimental \( \psi' \) and \( J/\psi \) production ratio in hadron-hadron collisions \([6,27]\). The results are illustrated in Fig. 3 by the upper two curves: the solid curve for parameters \( \sigma_{co}=4 \) mb, \( \tau_0=0.8 \) fm, and the dashed curve for \( \sigma_{co}=2 \) mb, \( \tau_0=1.0 \) fm. We see that the production ratio is insensitive to comover contributions. Moreover, in addition to nuclear absorption and comover contributions the EMC effects can be important at positive \( x_F \) in A-p collisions \([18]\). However, since the EMC effects are initial-state effects and should be independent of the final produced type of charmonium, the inclusion of the EMC effects will not affect the value of the production ratio \( R_{\psi'/\psi} \). The same argument exists for initial-state energy loss \([16]\). Therefore we suggest that the prediction of production ratio \( R_{\psi'/\psi} \) at positive \( x_F \) in A-p collisions should be able to provide a direct test for nuclear absorption scenario discussed above.

Another nuclear absorption scenario (Scenario-II) has been recently proposed by Kharzeev and Satz \([11]\), and shown to be able to derive the phenomenological Gerschel-Hüfner fit \([28]\) for hadron-nucleus data on \( J/\psi \) production. In this scenario charmonium state is considered to be produced through the intermediate next-to-leading Fock space component \( |(c\bar{c})_8g> \) formed by a colour octet \( c\bar{c} \) pair and a gluon, whose lifetime is estimated to be \( \tau_8 \simeq 0.25 \) fm. The interaction of the composite state \( (c\bar{c}g) \) with nucleons will lead to suppression of charmonium production. In particular, it is argued that the composite state \( (c\bar{c}g) \) is of the same size for all charmonium states, and hence the \( (c\bar{c}g) \)-nucleon cross section is the same for all charmonia. As a result, the production of \( J/\psi \) and \( \psi' \) will have the same suppression, as long as charmonium suppression is dominated by the interaction of the intermediate \( (c\bar{c}g) \) with nucleons. This is exactly what happens in the present p-A experiments.

However, this scenario may also predict different nuclear dependence of \( J/\psi \) and \( \psi' \) production in p-A collisions in the kinematic region where the composite state \( (c\bar{c}g) \) has turned into the fully formed charmonium bound states \( J/\psi \) and \( \psi' \), and then nuclear absorption will depend on the specific type of charmonium state. This will be shown in the following calculations.
Different from Scenario-I the nuclear absorption cross section in Scenario-II is now assumed to be

\[
\sigma_{abs}(z' - z) = \begin{cases} 
\sigma_{(c\bar{c}g)N} & \text{if } z' - z < \gamma v \tau_8, \\
\sigma_{RN} & \text{otherwise},
\end{cases}
\]  

(6)

where \(\gamma v\) is given by Eq. (3), \(\sigma_{RN}\) are the relevant nuclear absorption cross sections as the same as those in Eq. (2), \(\tau_8 \approx 0.25\) fm is the lifetime of the intermediate state \((c\bar{c}g)\) [29,11].

The cross section of the interaction between the intermediate state \((c\bar{c}g)\) and nucleons \(\sigma_{(c\bar{c}g)N}\) is estimated to be 6 - 7 mb [11]. We shall take \(\sigma_{(c\bar{c}g)N}=7\) mb in our calculations.

We have also in Scenario-II completed a calculation of the \(x_F\) dependence of \(\alpha\) in the parameterization Eq. (5) for \(J/\psi\) and \(\psi'\) production in p-A collisions at Fermilab E772/E789 energy. The results for chosen parameters, \(\sigma_{co}=4\) mb and \(\tau_0=0.8\) fm, are shown in Fig. 1 by the lower two curves: dot-dashed curve for \(J/\psi\) production and dotted curve for \(\psi'\) production. One sees that at \(x_F \gtrsim 0\), i.e. in the kinematic region covered by E772 data on \(J/\psi\) and \(\psi'\) production, Scenario-II also gives nearly the same nuclear dependence of \(J/\psi\) and \(\psi'\) production. On the other hand, a rather different nuclear dependence of \(J/\psi\) and \(\psi'\) production is predicted by Scenario-II at \(x_F \lesssim -0.1\). We can attribute this difference to the nuclear absorption dominated by the interaction of the fully formed \(J/\psi\) or \(\psi'\) bound states with target nucleons. However, the predicted \(J/\psi\) production at \(x_F \approx 0\) is more depleted than the E789 data, which might imply our over-estimate of the comover contributions in this region. The over-estimate, fortunately, will affect little the production ratio \(R_{\psi'}/\psi\), as it is shown below.

In Fig. 3 we show the calculated production ratio \(R_{\psi'}/\psi\) in A-p collisions at CERN-SPS energy based on Scenario-II by the lower two curves: dot-dashed curve with \(\sigma_{co}=4\) mb, \(\tau_0=0.8\) fm; and dotted curve with \(\sigma_{co}=2\) mb, \(\tau_0=1.0\) fm. Again one find that the production ratio \(R_{\psi'}/\psi\) given by Scenario-II is insensitive to comover contributions. Furthermore, the behavior of \(R_{\psi'}/\psi\) given by Scenario-II appears quite different from that predicted by Scenario-I, which is due to the following essential differences between Scenario-I and Scenario-II: First, in order that the \(J/\psi\) and \(\psi'\) production be equally suppressed at positive \(x_F\) in p-A colli-
sions, Scenario-I permits very little nuclear absorption cross section at $x_F \gtrsim 0$ for both $J/\psi$ and $\psi'$ production, while in Scenario-II the interaction cross section between the intermediate state $(c\bar{c}g)$ and nucleons is rather large but the same for $J/\psi$ and $\psi'$ production; Second, the proper formation time of physical $J/\psi$ and $\psi'$, $\tau_{\psi} \simeq 1.2$ fm and $\tau_{\psi'} \simeq 1.5$ fm, is rather long compared with the proper lifetime of the intermediate state $(c\bar{c}g)$, $\tau_8 \simeq 0.25$ fm, therefore the stronger suppression of $\psi'$ production relative to $J/\psi$ production in A-p collisions given by Scenario-II happens at lower value of $x_F$ than that given by Scenario-I (see Fig. 3). Based on the behavior of predicted $R_{\psi'/\psi}$, an experimental test of nuclear absorption scenarios is possible.

Although uncertainties of the parameters in nuclear absorption scenarios might reduce the power of prediction, some qualitative behaviors discussed here should be maintained by future experimental data. If not, e.g. the nuclear dependence of $J/\psi$ and $\psi'$ production remains the same at positive $x_F$ in A-p collisions, some nuclear absorption scenarios will be excluded as the explanation of quarkonium suppression observed in nuclear collisions.

To summary, we have shown in this work that nuclear absorption scenarios are able to predict different nuclear dependence of $J/\psi$ and $\psi'$ production at negative $x_F$ in p-A collisions or equivalently at positive $x_F$ in A-p collisions, although the present p-A data at $x_F \gtrsim 0$ observed the same nuclear dependence of $J/\psi$ and $\psi'$ production [5,6]. Furthermore, we find that the production ratio $\sigma(\psi')/\sigma(J/\psi)$ at positive $x_F$ in A-p collisions is mainly determined by nuclear absorption, but insensitive to comover contributions, initial-state energy loss and EMC effects, which can also contribute to charmonium production in this kinematic region. Therefore the predictions of production ratio at positive $x_F$ in A-p collisions are suggested to be able to provide a rather direct and experimentally accessible test for nuclear absorption scenarios.
REFERENCES

[1] T. Matsui and H. Satz, Phys. Lett. B178 (1986) 416.

[2] M. C. Abreu et al., Z. Phys. C38 (1988) 117.

[3] J. Y. Grossiord et al., Nucl. Phys. A498 (1989) 249c.

[4] C. Baglin et al., Phys. Lett. B220 (1989) 471; B255 (1991) 459; B262 (1991) 362; B270 (1991) 105.

[5] D. M. Alde et al., Phys. Rev. Lett. 66 (1991) 133.

[6] M. C. Abreu et al., Nucl. Phys. A566 (1994) 371c; C. Lourenço, Proc. Int. Workshop XXIII on Gross Properties of Nuclei and Nuclear Excitations, ed. H. Feldmeier and W. Nörenberg (Gesellschaft für Schwerionenforschung mbH, Darmstadt, 1995) p163.

[7] S. J. Brodsky and A. H. Mueller, Phys. Lett. B206 (1988) 685.

[8] J.-P. Blaizot and J.-Y. Ollitrault, Phys. Lett. B217 (1989) 386; J.-P. Blaizot, Nucl. Phys. A498 (1989) 273c.

[9] S. Gavin and R. Vogt, Nucl. Phys. B345 (1990) 104.

[10] R. Vogt, S. J. Brodsky and P. Hoyer, Nucl. Phys. B360 (1991) 67.

[11] D. Kharzeev and H. Satz, preprint CERN-TH/95-214, BI-TP 95/30.

[12] J. Qiu, Nucl. Phys. B291 (1987) 746.

[13] J. Ashman et al., Phys. Lett. B202 (1988) 603.

[14] S. J. Brodsky and H. J. Lu, Phys. Rev. Lett. 64 (1990) 1342.

[15] S. J. Brodsky and P. Hoyer, Phys. Rev. Lett. 63 (1989) 1566.

[16] S. Gavin and J. Milana, Phys. Rev. Lett. 68 (1992) 1834.

[17] J.J. Aubert et al., Phys. Lett B123 (1983) 275; A. C. Benvenuti et al., Phys. Lett.
[18] D. Kharzeev and H. Satz, preprint CERN-TH/95-73 BI-TP 95/16.

[19] W. Q. Chao, C. S. Gao and Y. B. He, preprint CCAST-95-06.

[20] M. J. Leitch et al., Phys. Rev. Lett. 72 (1994) 2542.

[21] P. Hoyer, preprint NORDITA-95/78 P, hep-ph/9511411.

[22] W. Kwong, J. L. Rosner and C. Quigg, Annu. Rev. Nucl. Part. Sci. 37 (1987) 325.

[23] F. Karsch and R. Petronzio, Z. Phys. C37 (1988) 627.

[24] S. Gavin, H. Satz, R. L. Thews and R. Vogt, Z. Phys. C61 (1994) 351.

[25] B. Povh and J. H"ufner, Phys. Rev. Lett. 58 (1987) 1612.

[26] M. J. Leitch et al., Nucl. Phys. A544 (1992) 197c.

[27] R. Gavai et al., in Hard Processes in Hadronic Interactions, Ed. H. Satz and X.-N. Wang; Preprint CERN-TH.7526/94, BI-TP 63/94.

[28] C. Gerschel and J. H"ufner, Z. Phys. C56 (1992) 171.

[29] D. Kharzeev and H. Satz, Z. Phys. C60 (1993)389.
FIGURE CAPTIONS

Fig. 1. Predictions for $J/\psi$ and $\psi'$ production in the Fermilab E772/E789 experiment with 800 GeV/c proton-beam incident on nuclear targets: the upper two curves given by Scenario-I (solid curve for $J/\psi$ and dashed curve for $\psi'$) the lower two curves given by Scenario-II (dot-dashed curve for $J/\psi$ and dotted curve for $\psi'$). Also shown are the Fermilab E789 data on the $J/\psi$ production [26].

Fig. 2. Predictions given by Scenario-I for $J/\psi$ and $\psi'$ production in the CERN-SPS experiment with 160 GeV/c $Pb$-beam incident on a hydrogen target for two sets of parameters $\sigma_{co}$ and $\tau_0$ in comover contributions: the upper two curves with $\sigma_{co}=2$ mb and $\tau_0=1.0$ fm (dot-dashed curve for $\alpha_{J/\psi}$ and dotted curve for $\alpha_{\psi'}$); the lower two curves with $\sigma_{co}=4$ mb and $\tau_0=0.8$ fm (dot-dashed curve for $\alpha_{J/\psi}$ and dotted curve for $\alpha_{\psi'}$).

Fig. 3. Predictions of the production ratio for $J/\psi$ and $\psi'$ production in the CERN-SPS experiment with 160 GeV/c $Pb$-beam incident on a hydrogen target given by Scenario-I (the upper two curves: the solid curve for parameters $\sigma_{co}=4$ mb, $\tau_0=0.8$ fm, and the dashed curve for $\sigma_{co}=2$ mb, $\tau_0=1.0$ fm) and Scenario-II (the lower two curves: dot-dashed curve with $\sigma_{co}=4$ mb, $\tau_0=0.8$ fm; and dotted curve with $\sigma_{co}=2$ mb, $\tau_0=1.0$ fm).
