Vol. 32 (2001) ACTA PHYSICA POLONICA B No 12

J/Ψ SUPPRESSION IN AN EXPANDING HADRON GAS* **

Dariusz Prorok

Institute of Theoretical Physics, University of Wrocław
Pl. Maksa Borna 9, 50-204 Wrocław, Poland

(Received July 23, 2001)

A model for J/Ψ suppression at a high energy heavy ion collision is presented. The main (and the only) reason for the suppression is J/Ψ inelastic scattering within hadron matter. The hadron matter is in the form of a multi-component non-interacting gas. Also the evolution of the gas, both longitudinal and transverse, is taken into account. It is shown that under such circumstances and with J/Ψ disintegration in nuclear matter added, J/Ψ suppression evaluated agrees well with NA38 and NA50 data.

PACS numbers: 14.40.Lb, 24.10.Pa, 25.75.–q

1. Introduction

On the 10th of February 2000 CERN announced the discovery of the novel state of matter — the so-called Quark–Gluon Plasma (QGP). The existence of the QGP has been predicted upon lattice QCD calculations (for a review see [2] and references therein) and the critical temperature $T_{\rm c}$ for the ordinary hadron matter-QGP phase transition has been estimated in the range of 150–270 MeV (this corresponds to the broad range of the critical energy density $\varepsilon_{\rm c} \simeq 0.26$–$5.5$ GeV/fm^3). The upper limit belongs to a pure SU(3) theory, whereas adding quarks causes lowering of $T_{\rm c}$ even to about 150 MeV ($\varepsilon_{\rm c} \simeq 0.26$ GeV/fm^3 respectively). Since NA50 Collaboration estimates for the energy density obtained in the Central Rapidity Region (CRR) give the value of 3.5 GeV/fm^3 for the most central Pb–Pb data point [3], it is argued that the region of the existence of the QGP has been reached in Pb–Pb collisions at CERN SPS.

Soon after the announcement, the paper entitled "Evidence for deconfinement of quarks and gluons from the J/Ψ suppression pattern measured

* Presented at the XLI Cracow School of Theoretical Physics, Zakopane, Poland, June 2–11, 2001.

** Talk based on the work done in collaboration with L. Turko [1].

in Pb–Pb collisions at the CERN-SPS" appeared [3]. As the title suggests, the main argument for the QGP creation during Pb–Pb collisions at the CERN SPS is the observation of the suppression of J/Ψ relative yield. J/Ψ suppression as a signal for the QGP formation was originally proposed by Matsui and Satz [4]. The clue point of the NA50 Collaboration paper is the figure (denoted as Fig. 6 there), where experimental data for Pb–Pb collision values of $\frac{B_{\mu\mu}\sigma_{J/\psi}}{\sigma_{\rm DY}}$ (the ratio of the J/Ψ to the Drell–Yan production cross-section times the branching ratio of the J/Ψ into a muon pair) are presented together with some conventional predictions. Here, "conventional" means that J/Ψ suppression is due to J/Ψ absorption in ordinary hadron matter. Since all those conventional curves saturate at high transverse energy $E_{\rm T}$, but the experimental data fall from $E_{\rm T} \simeq 90$ GeV much lower and this behaviour could be reproduced on the base of J/Ψ disintegration in QGP [5], it is argued that QGP had to appear during most central Pb–Pb collisions. In general, the immediate reservation about such reasoning is that besides those already known (see *e.g.* [6–10] and references [12–15] in [3]), there could be a huge number of different conventional models, so until this subject is cleared up completely, no one is legitimate to ruled out the absorption picture of J/Ψ suppression.

In the following talk, the more systematic and general description of J/Ψ absorption in the framework of statistical analysis will be presented. The main features of the model are [1]:

1. A multi-component non-interacting hadron gas appears in the CRR instead of the QGP;
2. the gas expands longitudinally and transversely;
3. J/Ψ suppression is the result of inelastic scattering on constituents of the gas and on nucleons of colliding ions.

2. The timetable of events in the CRR

For a given A–B collision $t = 0$ is fixed at the moment of the maximal overlap of the nuclei (for more details see *e.g.* [9]). As nuclei pass each other charmonium states are produced as the result of gluon fusion. After half of the time the nuclei need to cross each other ($t \sim 0.5$ fm), matter appears in the CRR. It is assumed that the matter thermalizes almost immediately and the moment of thermalization, t_0, is estimated at about 1 fm [9, 11]. Then the matter begins its expansion and cooling and after reaching the freeze-out temperature, $T_{\rm f.o.}$, it ceases as a thermodynamical system. The moment when the temperature has decreased to $T_{\rm f.o.}$ is denoted as $t_{\rm f.o.}$. Since the matter under consideration is the hadron gas, any phase transition does not take place during cooling here.

For the description of the evolution of the matter, relativistic hydrodynamic is explored. The longitudinal component of the solution of hydrodynamic equations (the exact analytic solution for an (1+1)-dimensional case) reads (for details see *e.g.* [11, 12])

$$s(\tau) = \frac{s_0 \tau_0}{\tau}\,, \qquad n_B(\tau) = \frac{n_B^0 \tau_0}{\tau}\,, \qquad v_z = \frac{z}{t}\,, \tag{1}$$

where $\tau = \sqrt{t^2 - z^2}$ is a local proper time, v_z is the z-component of fluid velocity (z is a collision axis) and s_0 and n_B^0 are initial densities of the entropy and the baryon number, respectively. For $n_B = 0$ and the uniform initial temperature distribution with the sharp edge at the border established by nuclei radii, the full solution of (3+1)-dimensional hydrodynamic equations is known [13]. The evolution derived is the decomposition of the longitudinal expansion inside a slice bordered by the front of the rarefaction wave and the transverse expansion which is superimposed outside of the wave. Because small but nevertheless non-zero baryon number densities are considered here, the above-mentioned description of the evolution has to be treated as an assumption in the presented model. The rarefaction wave moves radially inward with a sound velocity $c_{\rm s}$. The sound velocity squared is given by $c_{\rm s}^2 = \frac{\partial P}{\partial \varepsilon}$ and can be evaluated numerically [14, 15].

3. The multi-component hadron gas

For an ideal hadron gas in thermal and chemical equilibrium, which consists of l species of particles, energy density ε, baryon number density n_B, strangeness density n_S and entropy density s read ($\hbar = c = 1$ always)

$$\varepsilon = \frac{1}{2\pi^2} \sum_{i=1}^{l} (2s_i + 1) \int_0^\infty dp \, \frac{p^2 E_i}{\exp\left\{\frac{E_i - \mu_i}{T}\right\} + g_i}\,, \tag{2a}$$

$$n_B = \frac{1}{2\pi^2} \sum_{i=1}^{l} (2s_i + 1) \int_0^\infty dp \, \frac{p^2 B_i}{\exp\left\{\frac{E_i - \mu_i}{T}\right\} + g_i}\,, \tag{2b}$$

$$n_S = \frac{1}{2\pi^2} \sum_{i=1}^{l} (2s_i + 1) \int_0^\infty dp \, \frac{p^2 S_i}{\exp\left\{\frac{E_i - \mu_i}{T}\right\} + g_i}\,, \tag{2c}$$

$$s = \frac{1}{6\pi^2 T^2} \sum_{i=1}^{l} (2s_i + 1) \int_0^\infty dp \, \frac{p^4}{E_i} \frac{(E_i - \mu_i) \exp\left\{\frac{E_i - \mu_i}{T}\right\}}{\left(\exp\left\{\frac{E_i - \mu_i}{T}\right\} + g_i\right)^2}\,, \tag{2d}$$

where $E_i = (m_i^2 + p^2)^{1/2}$ and m_i, B_i, S_i, μ_i, s_i and g_i are the mass, baryon number, strangeness, chemical potential, spin and a statistical factor of specie i, respectively (an antiparticle is treated as a different specie). And $\mu_i = B_i\mu_B + S_i\mu_S$, where μ_B and μ_S are overall baryon number and strangeness chemical potentials, respectively.

To obtain the time dependence of temperature and baryon number and strangeness chemical potentials one has to solve numerically Eqs. (2b)–(2d) with s, n_B and n_S given as time dependent quantities. For $s(\tau)$ and $n_B(\tau)$ expressions (1) are taken and $n_S = 0$ since the overall strangeness equals zero during all the evolution (for more details see [14]).

4. J/Ψ absorption in the expanding hadronic gas

As it has been already mentioned in Sect. 2 charmonium states are produced in the beginning of the collision, when nuclei overlap. For simplicity, it is assumed that the production of $c\bar{c}$ states takes place at $t = 0$. To describe J/Ψ absorption quantitatively, the idea of [9] is generalized to the case of the multi-component massive gas, here. Since in the CRR longitudinal momenta of particles are much lower than transverse ones (in the c.m.s. frame of nuclei), J/Ψ longitudinal momentum is put at zero. Additionally, only the plane $z = 0$ is under consideration, here. For the simplicity of the model, it is assumed that all charmonium states are completely formed and can be absorbed by the constituents of a surrounding medium from the moment of creation. The absorption is the result of a $c\bar{c}$ state inelastic scattering on the constituents of the hadron gas through interactions of the type

$$c\bar{c} + h \longrightarrow D + \bar{D} + X \,, \tag{3}$$

where h denotes a hadron, D is a charm meson and X means a particle which is necessary to conserve the charge, baryon number or strangeness.

Since the most crucial for the problem of QGP existence are Pb–Pb collisions (see remarks in Sect. 1), the further considerations are done for this case. So, for the Pb–Pb collision at impact parameter b, the situation in the plane $z = 0$ is presented in Fig. 1, where S_{eff} means the area of the overlap of the colliding nuclei.

Additionally, it is assumed that the hadron gas, which appears in the space between the nuclei after they have crossed each other, also has the shape of S_{eff} at t_0 in the plane $z = 0$. Then, the transverse expansion starts in the form of the rarefaction wave moving inward S_{eff} at t_0.

From the considerations based on the relativistic kinetic equation (for details see [1,9]), the survival fraction of J/Ψ in the hadron gas as a function

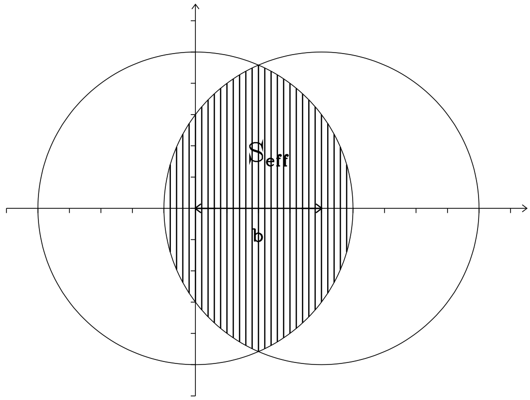

Fig. 1. View of a Pb–Pb collision at impact parameter b in the transverse plane ($z = 0$). The region where the nuclei overlap is hatched and denoted by S_{eff}.

of the initial energy density ε_0 in the CRR is obtained:

$$\mathcal{N}_{\mathrm{h.g.}}(\varepsilon_0) = \int dp_{\mathrm{T}}\; g(p_{\mathrm{T}}, \varepsilon_0)\; \exp\left\{ - \int\limits_{t_0}^{t_{\mathrm{final}}} dt \sum_{i=1}^{l} \int \frac{d^3\vec{q}}{(2\pi)^3} f_i(\vec{q}, t)\sigma_i v_{\mathrm{rel},i} \frac{p_\nu q_i^\nu}{E E_i'} \right\}, \tag{4}$$

where the sum is over all taken species of scatters (hadrons), $p^\nu = (E, \vec{p}_{\mathrm{T}})$ and $q_i^\nu = (E_i', \vec{q})$ are four momenta of J/Ψ and hadron specie i, respectively, σ_i states for the absorption cross-section of $J/\Psi - h_i$ scattering, $v_{\mathrm{rel},i}$ is the relative velocity of h_i hadron with respect to J/Ψ and M and m_i denote J/Ψ and h_i masses respectively ($M = 3097$ MeV). The function $g(p_{\mathrm{T}}, \varepsilon_0)$ is the J/Ψ initial momentum distribution. It has a Gaussian form and reflects gluon multiple elastic scatterings on nucleons before their fusion into a J/Ψ in the first stage of the collision [16–19]. The upper limit of the integration over time in (4), namely t_{final} is the minimal value of $\langle t_{\mathrm{esc}} \rangle$ and $t_{\mathrm{f.o.}}$. The quantity $\langle t_{\mathrm{esc}} \rangle$ is the average time of the escape of J/Ψ's from the hadron medium for given values of b and J/Ψ velocity $\vec{v} = \vec{p}_{\mathrm{T}}/E$. Note that the average is taken with the weight

$$p_{J/\Psi}(\vec{r}) = \frac{T_A(\vec{r})T_B(\vec{r} - \vec{b})}{T_{AB}(b)}\,, \tag{5}$$

where $T_{AB}(b) = \int d^2\vec{s}\; T_A(\vec{s})T_B(\vec{s} - \vec{b})$, $T_A(\vec{s}) = \int dz \rho_A(\vec{s}, z)$ and $\rho_A(\vec{s}, z)$ is the nuclear matter density distribution. For the last quantity, the Woods–Saxon nuclear matter density distribution with parameters from [20] is taken.

In the integration over hadron momentum in (4) the threshold for the reaction (3) is included, *i.e.* σ_i equals zero for $(p^\nu + q_i^\nu)^2 < (2m_D + m_X)^2$ and is constant elsewhere (m_D is a charm meson mass, $m_D = 1867$ MeV). Also the usual Bose–Einstein or Fermi–Dirac distribution for hadron specie i is used in (4)

$$f_i(\vec{q}, t) = f_i(q, t) = \frac{2s_i + 1}{\exp\left\{\frac{E_i' - \mu_i(t)}{T(t)}\right\} + g_i} \,. \tag{6}$$

As far as σ_i is concerned, there are no data for every particular $J/\Psi - h_i$ scattering. Therefore, only two types of the cross-section, the first, σ_b, for J/Ψ-baryon scattering and the second, σ_m, for J/Ψ-meson scattering are assumed, here. In the model presented σ_b is put at $\sigma_{J/\psi N}$ — J/Ψ-Nucleon absorption cross-section. And values of $\sigma_{J/\psi N}$ in the range of 3–5 mb are taken from p–A data [21–23]. The J/Ψ-meson cross-section σ_m is assumed to be 2/3 of σ_b, which is due to the quark counting.

As it has been already suggested [21] also J/Ψ scattering in nuclear matter should be included in any J/Ψ absorption model. This could be done with the introduction of J/Ψ survival factor in nuclear matter [23–26]

$$\mathcal{N}_{\rm n.m.}(\varepsilon_0) \cong \exp\left\{-\sigma_{J/\psi N}\rho_0 L\right\} \,, \tag{7}$$

where ρ_0 is the nuclear matter density and L the mean path length of the J/Ψ through the colliding nuclei. The length L is expressed by the following formula [26]:

$$\rho_0 L(b) = \frac{1}{2T_{AB}} \int d^2\vec{s}\, T_A(\vec{s}) T_B(\vec{s} - \vec{b}) \left[\frac{A-1}{A} T_A(\vec{s}) + \frac{B-1}{B} T_B(\vec{s} - \vec{b})\right] . \tag{8}$$

Since J/Ψ absorptions: in nuclear matter and in the hadron gas, are separate in time, J/Ψ survival factor for a heavy-ion collision with the initial energy density ε_0, could be defined as

$$\mathcal{N}(\varepsilon_0) = \mathcal{N}_{\rm n.m.}(\varepsilon_0)\, \mathcal{N}_{\rm h.g.}(\varepsilon_0) \,. \tag{9}$$

Note that since right sides of (4) and (7) include parts which depend on impact parameter b and the left sides are functions of ε_0 only, the expression converting the first quantity to the second (or reverse) should be given. This is done with the use of the dependence of ε_0 on the transverse energy $E_{\rm T}$ extracted from NA50 data [3] (for details see [1]).

To make the model as much realistic as possible, one should keep in mind that only about 60% of J/Ψ's measured are directly produced during collision. The rest is the result of χ ($\sim 30\%$) and ψ' ($\sim 10\%$) decay [27]. Therefore the realistic J/Ψ survival factor could be expressed as

$$\mathcal{N}(\varepsilon_0) = 0.6\mathcal{N}_{J/\psi}(\varepsilon_0) + 0.3\mathcal{N}_{\chi}(\varepsilon_0) + 0.1\mathcal{N}_{\psi'}(\varepsilon_0) \,, \tag{10}$$

where $\mathcal{N}_{J/\psi}(\varepsilon_0)$, $\mathcal{N}_{\chi}(\varepsilon_0)$ and $\mathcal{N}_{\psi'}(\varepsilon_0)$ are given also by formulae (4), (7) and (9) but with $g(p_{\mathrm{T}}, \varepsilon_0)$, $\sigma_{J/\psi N}$ and M changed appropriately (for details see [1]).

To complete, also values of cross-sections for χ-baryon and ψ'-baryon scatterings are needed. For simplicity, it is assumed that both these cross-sections are equal to J/Ψ-baryon one. Since J/Ψ is smaller than χ or ψ', this means that J/Ψ suppression evaluated according to (10) is *underestimated* here.

5. Results

To calculate formula (4) initial values s_0 and n_B^0 are needed. For the estimation of the last quantity experimental results for S–S [28] and Au–Au [29, 30] collisions are explored. The S–S data give $n_B^0 \cong 0.25\ \mathrm{fm}^{-3}$ and Au–Au data $n_B^0 \cong 0.65\ \mathrm{fm}^{-3}$. These values are for central collisions, for more peripheral ones the initial baryon number density should be lower. To simplify numerical calculations, n_B^0 is kept constant over the whole range of b. But, to check the possible dependence on n_B^0, also the much lower value $n_B^0 = 0.05\ \mathrm{fm}^{-3}$ is examined. To find s_0, (2a)–(2c) with respect to T, μ_S and μ_B are solved. Then, having put T_0, μ_S^0 and μ_B^0 into (2d), s_0 is obtained. The last parameter of the model is the freeze-out temperature. Two values $T_{\mathrm{f.o.}} = 100, 140$ MeV are taken here and they agree well with estimates based on hadron yields [29].

Firstly, formula (10) with the use of (4) only instead of (9) is calculated for the case of (1+1)-dimensional expansion and results are presented in Figs. 2–3.

For comparison, also the experimental data are shown in Figs. 2–3. The experimental survival factor is defined as

$$\mathcal{N}_{\mathrm{exp}} = \frac{\frac{B_{\mu\mu}\sigma^{AB}_{J/\psi}}{\sigma^{AB}_{\mathrm{DY}}}}{\frac{B_{\mu\mu}\sigma^{pp}_{J/\psi}}{\sigma^{pp}_{\mathrm{DY}}}}\,, \tag{11}$$

where $\frac{B_{\mu\mu}\sigma^{AB(pp)}_{J/\psi}}{\sigma^{AB(pp)}_{\mathrm{DY}}}$ is the ratio of the J/Ψ to the Drell–Yan production cross-section in A–B(p–p) interactions times the branching ratio of the J/Ψ into a muon pair. The values of the ratio for p–p, S–U and Pb–Pb are taken from [3, 31, 32]. The results of numerical evaluations of (10) agree with the data well qualitatively for greater baryonic cross-section σ_b and (or) for the lower freeze-out temperature $T_{\mathrm{f.o.}}$, except the last point measured for the highest E_{T} bin.

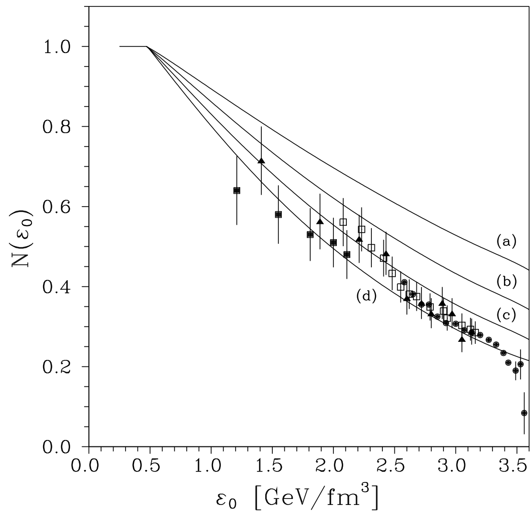

Fig. 2. J/Ψ suppression in the longitudinally expanding hadron gas for $n_B^0 = 0.25$ fm^{-3} and $T_{\rm f.o.} = 140$ MeV: (a) $\sigma_b = 3$ mb, $\sigma_m = 2$ mb; (b) $\sigma_b = 4$ mb, $\sigma_m = 2.66$ mb; (c) $\sigma_b = 5$ mb, $\sigma_m = 3.33$ mb; (d) $\sigma_b = 6$ mb, $\sigma_m = 4$ mb . The black squares correspond to the NA38 S-U data [31], the black triangles correspond to the 1996 NA50 Pb–Pb data, the white squares to the 1996 analysis with minimum bias and the black points to the 1998 analysis with minimum bias [3].

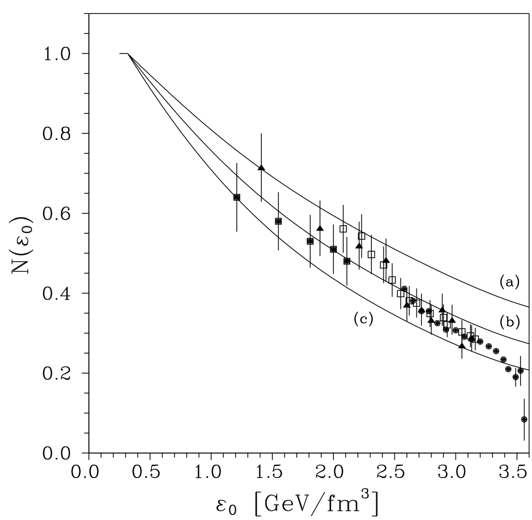

Fig. 3. Same as Fig. 2 (except case (d), which is not presented here) but for $T_{\rm f.o.} = 100$ MeV.

Now the full (3+1)-dimensional hydrodynamic evolution (in the form described in Sect. 2) and J/Ψ absorption in nuclear matter will be taken into account and results are depicted in Figs. 4–5. To draw also S–U data together with Pb–Pb ones, instead of multiplying $\mathcal{N}_{\mathrm{h.g.}}$ by $\mathcal{N}_{\mathrm{n.m.}}$, $\mathcal{N}_{\mathrm{exp}}$ is divided by $\mathcal{N}_{\mathrm{n.m.}}$, *i.e.* "the experimental J/Ψ hadron gas survival factor" is defined as

$$\tilde{\mathcal{N}}_{\mathrm{exp}} = \exp\left\{\sigma_{J/\psi N}\rho_0 L\right\}\mathcal{N}_{\mathrm{exp}}\ , \tag{12}$$

and values of this factor are drawn in Figs. 4–5 as the experimental data. The quantity r_0 is a parameter from the expression for a nucleus radius $R_A = r_0 A^{1/3}$. The value of R_A is used to fix the initial position of the rarefaction wave in the evaluation of $\langle t_{\mathrm{esc}}\rangle$ in (4). It has turned out that the case of $n_B^0 = 0.05\ \mathrm{fm}^{-3}$ does not differ substantially from that of $n_B^0 = 0.25\ \mathrm{fm}^{-3}$, so curves for $n_B^0 = 0.05\ \mathrm{fm}^{-3}$ are not depicted in Figs. 4–5.

Having compared Figs. 4–5 with Figs. 2–3, one can see that adding the transverse expansion changes the final (theoretical) pattern of J/Ψ suppression qualitatively. Now the curves for the case including the transverse expansion are not convex, in opposite to the case with the longitudinal ex-

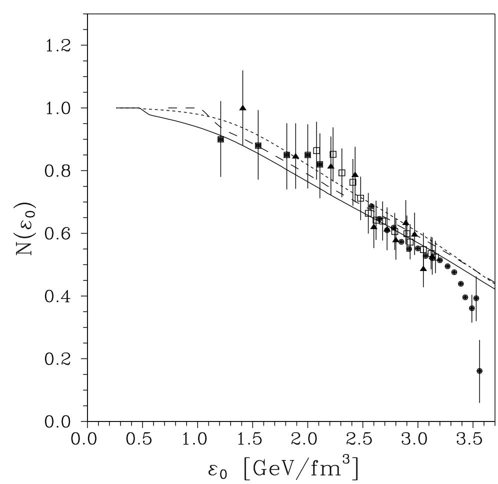

Fig. 4. J/Ψ suppression in the longitudinally and transversely expanding hadron gas for the Woods–Saxon nuclear matter density distribution and $\sigma_b = 4$ mb, $\sigma_m = 2.66$ mb and $T_{\mathrm{f.o.}} = 140$ MeV. The curves correspond to $n_B^0 = 0.25\ \mathrm{fm}^{-3}$, $c_s = 0.45$, $r_0 = 1.2$ fm (solid), $n_B^0 = 0.65\ \mathrm{fm}^{-3}$, $c_s = 0.46$, $r_0 = 1.2$ fm (dashed) and $n_B^0 = 0.25\ \mathrm{fm}^{-3}$, $c_s = 0.45$, $r_0 = 1.12$ fm (short-dashed). The black squares represent the NA38 S–U data [31], the black triangles represent the 1996 NA50 Pb–Pb data, the white squares the 1996 analysis with minimum bias and the black points the 1998 analysis with minimum bias [3], but the data are "cleaned out" from the contribution of J/Ψ scattering in the nuclear matter in accordance with (12).

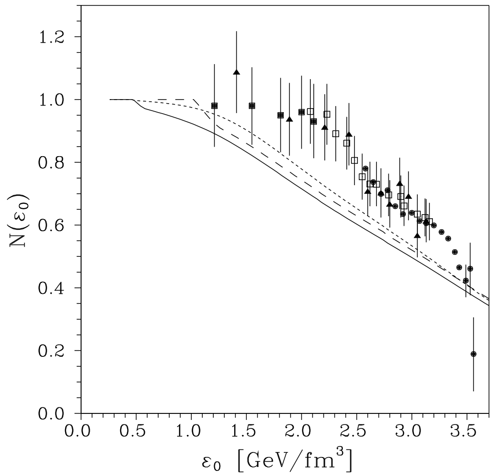

Fig. 5. Same as Fig. 4 but for $\sigma_b = 5$ mb and $\sigma_m = 3.33$ mb.

pansion only, where the curves are. As far as the pattern of suppression is concerned, theoretical curves do not fall steep enough at high ε_0 to cover the data area. But for some choice of parameters, namely for σ_b somewhere between 4 and 5 mb and for $r_0 = 1.12$ fm, a quite satisfactory curve could have been obtained. Precisely, again only the highest E_{T} bin point falls down of the range of theoretical estimates completely. But the error bar of this point is very wide. And also the contradiction in positions of the last three points of the 1998 data can be seen. This means that the high E_{T} region should be measured once more with the better accuracy to state definitely whether the abrupt fall of the experimental survival factor takes place or not there.

To support the conclusion, main results from Figs. 4–5 are presented in Fig. 6 again. The original data [3] for $\frac{B_{\mu\mu}\sigma_{J/\psi}^{\mathrm{PbPb}}}{\sigma_{\mathrm{DY}}^{\mathrm{PbPb}}}$ and J/Ψ survival factors given by (10) multiplied by $\frac{B_{\mu\mu}\sigma_{J/\psi}^{pp}}{\sigma_{\mathrm{DY}}^{pp}}$ and now as functions of E_{T} are depicted there (for details see [1]). As it has been already mentioned, the main disagreement with the data appears in the last experimental point of the 1998 analysis.

The charmonium-baryon inelastic cross-section is the most crucial parameter in the model presented. So to be sure what is the exact result of J/Ψ absorption, one should know how this cross-section behaves in the hot hadron environment. The newest estimations of $\pi + J/\Psi$, $\rho + J/\Psi$ and $J/\Psi + N$ cross-sections at high invariant collision energies [33, 34] give values of σ_b and σ_m of the same order as assumed here. Also it should be

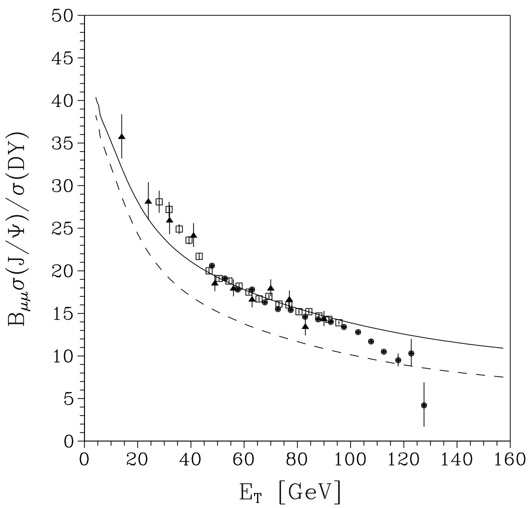

Fig. 6. J/Ψ survival factor times $\frac{B_{\mu\mu}\sigma^{pp}_{J/\psi}}{\sigma^{pp}_{\rm DY}}$ in the longitudinally and transversely expanding hadron gas for the Woods–Saxon nuclear matter density distribution and $n_B^0 = 0.25$ fm^{-3}, $T_{\rm f.o.} = 140$ MeV, $c_s = 0.45$ and $r_0 = 1.2$ fm. The curves correspond to $\sigma_b = 4$ mb (solid) and $\sigma_b = 5$ mb (dashed). The black triangles represent the 1996 NA50 Pb–Pb data, the white squares the 1996 analysis with minimum bias and the black points the 1998 analysis with minimum bias [3].

stressed that the charmonium-hadron inelastic cross-sections are considered as constant quantities in the model presented. But, as the results of just mentioned papers suggest, they are not constant at all. The cross-sections are growing functions of the invariant collision energy $\sqrt{s}$. Therefore, one could think naively that the increase of ε_0 (or in other words $E_{\rm T}$) causes the increase of the invariant collision energy $\sqrt{s}$ on the average and further the increase of the charmonium-hadron inelastic cross-sections. In this way, the line describing J/Ψ survival factor could be placed close to the solid curve of Fig. 6 for low ε_0 ($E_{\rm T}$), and then, as the charmonium-hadron inelastic cross-sections increase, this line would go closer to the dashed curve of Fig. 6 for high ε_0 ($E_{\rm T}$). So, the experimental pattern of J/Ψ suppression could be recovered.

As the last remark, the author would like to call reader's attention to Fig. 5 of [35]. The solid and dotted curves in that figure are exactly the same as curves just presented in Fig. 6. But the distortion in the QGP is the main reason for J/Ψ suppression in [35]! It is also stated there, that results shown "provide evidence for the production of the quark–gluon plasma in central high-energy Pb–Pb collisions".

Therefore, the final conclusion is the following: the NA50 Pb–Pb data provides evidence for the production of the thermalized and *confined* hadron gas in the central rapidity region of a Pb–Pb collision. This implies that J/Ψ suppression is not a good signal for the quark–gluon plasma appearance at a central heavy-ion collision.

REFERENCES

[1] D. Prorok, L. Turko, *Phys. Rev.* **C64**, 044903 (2001).

[2] F. Karsch, `hep-ph/0103314`; *Nucl. Phys. Proc. Suppl.* **83**, 14 (2000).

[3] M.C. Abreu *et al.* [NA50 Collaboration], *Phys. Lett.* **B477**, 28 (2000).

[4] T. Matsui, H. Satz, *Phys. Lett.* **B178**, 416 (1986).

[5] H. Satz, *Nucl. Phys.* **A661**, 104c (1999).

[6] J. Ftáčnik, P. Lichard, J. Pišút, *Phys. Lett.* **B207**, 194 (1988).

[7] R. Vogt, M. Prakash, P. Koch, T.H. Hansson, *Phys. Lett.* **B207**, 263 (1988).

[8] S. Gavin, M. Gyulassy, A. Jackson, *Phys. Lett.* **B207**, 257 (1988).

[9] J.P. Blaizot, J.Y. Ollitrault, *Phys. Rev.* **D39**, 232 (1989).

[10] R. Vogt, *Phys. Rep.* **310**, 197 (1999).

[11] J.D. Bjorken, *Phys. Rev.* **D27**, 140 (1983).

[12] J. Cleymans, R.V. Gavai, E. Suhonen, *Phys. Rep.* **130**, 217 (1986).

[13] G. Baym, B.L. Friman, J.P. Blaizot, M. Soyeur, W. Czyż, *Nucl. Phys.* **A407**, 541 (1983).

[14] D. Prorok, L. Turko, *Z. Phys.* **C68**, 315 (1995).

[15] D. Prorok, L. Turko, `hep-ph/0101220`.

[16] J. Hufner, Y. Kurihara, H.J. Pirner, *Phys. Lett.* **B215**, 218 (1988).

[17] S. Gavin, M. Gyulassy, *Phys. Lett.* **B214**, 241 (1988).

[18] J.P. Blaizot, J.Y. Ollitrault, *Phys. Lett.* **B217**, 392 (1989).

[19] S. Gupta, H. Satz, *Phys. Lett.* **B283**, 439 (1992).

[20] C.W. de Jager, H. de Vries, C. de Vries, *Atomic Data and Nuclear Data Tables* **14**, 479 (1974).

[21] C. Gerschel, J. Hüfner, *Phys. Lett.* **B207**, 253 (1988).

[22] J. Badier *et al.* [NA3 Collaboration], *Z. Phys.* **C20**, 101 (1983).

[23] S. Gavin, R. Vogt, *Phys. Rev. Lett.* **78**, 1006 (1997).

[24] C. Gerschel, J. Hüfner, *Z. Phys.* **C56**, 171 (1992).

[25] S. Gavin, `hep-ph/9609470`.

[26] F. Bellaiche, PhD Thesis, Université Claude Bernard Lyon-I, Lyon, 1997; F. Fleuret, PhD Thesis, Ecole Polytechnique, Palaiseau, 1997

[27] H. Satz, `hep-ph/9711289`.

[28] J. Baechler *et al.* [NA35 Collaboration], *Nucl. Phys.* **A525**, 59C (1991).

[29] J. Stachel, *Nucl. Phys.* **A654**, 119c (1999).

[30] L. Ahle *et al.* [E802 Collaboration], *Phys. Rev.* **C57**, R466 (1998).

[31] M.C. M.C. Abreu *et al.* [NA38 Collaboration], *Phys. Lett.* **B449**, 128 (1999); M.C. Abreu *et al.*, *Phys. Lett.* **B466**, 408 (1999).

[32] M.C. Abreu *et al.* [NA50 Collaboration], *Phys. Lett.* **B450**, 456 (1999).

[33] K. Tsushima, A. Sibirtsev, K. Saito, A.W. Thomas, D.H. Lu, *Nucl. Phys.* **A680**, 279 (2000).

[34] A. Sibirtsev, K. Tsushima, A. W. Thomas, *Phys. Rev.* **C63**, 044906 (2001).

[35] C. Wong, *Nucl. Phys.* **A681**, 22 (2001).