Contribution of intermediate stage gluons to $J/\Psi$ suppression in Lead-Lead collisions at 158AGeV

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Abstract

We point out that dissociation of $J/\Psi$ by partons (mostly gluons) present in the intermediate stage of heavy-ion collisions can explain $J/\Psi$ suppression observed recently by the NA-50 Collaboration at the CERN-SPS in Pb-Pb interactions. Suppression by intermediate stage gluons represents an additional multiplicative factor to that given by Gerschel-Hüfner mechanism. The agreement with data on $J/\Psi$ suppression both in light-ions induced nuclear collisions and in Pb-Pb interactions requires that the life-time of intermediate stage gluons increases with the nucleon numbers of colliding nuclei.

In our model the energy density of intermediate stage gluons in Pb-Pb collisions approaches for a short time the critical density.

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1 Introduction

Suppression of $J/\Psi$ in heavy-ion collisions has been suggested as a signature of Quark-Gluon Plasma by Matsui and Satz [1] a decade ago. A sizeable suppression has been really observed by the NA-38 Collaboration [2] in collisions of Oxygen and Sulphur ions with heavy nuclei.

As alternative explanations, suppression of $J/\Psi$ by thermalized hadron gas [3,4] or by nucleons present in nuclei [5] have been suggested. New experimental data [6,7] on the A-dependence of $J/\Psi$ production in hadron-nucleus collisions have shown that the cross-section for $J/\Psi$ disintegration in a collision with a fast nucleon is about 6mb. This has permitted to Gerschel and Hüfner [5] to describe satisfactorily the data on $J/\Psi$ suppression in hadron- and light ion- collisions with heavy nuclei by disintegration of $J/\Psi$ in collisions with nucleons.

The recent results of the NA-50 group show [8] that the $J/\Psi$ suppression in Pb-Pb collisions at laboratory energy of 158 GeV per nucleon is by a factor of two stronger than that given by the extrapolation of the Gerschel-Hüfner curve. Moreover, $J/\Psi$ suppression depends rather strongly on centrality of Pb-Pb collision.

In this situation it is natural to search for a mechanism which would be able to provide the additional $J/\Psi$ suppression in Pb-Pb without increasing significantly the suppression in collisions of lighter ions.

In early work [3,4] authors have studied $J/\Psi$ suppression by a thermalized hadron gas. In view of recent studies by Kharzeev,Satz and McLerran [9] it seems that cross-sections for the disintegration of $J/\Psi$ by hadrons in a thermalized hadron gas with temperatures of 150- 200MeV are rather low so one is inclined to search the relevant mechanism in the intermediate stage of heavy-ion collision. Out of possible candidates one can think of at least two possibilities:

The former is the disintegration of $J/\Psi$ by fast secondary hadrons (mostly pions). In a larger system, like Pb-Pb, some secondary pions have more time to complete their formation [10] and are able to disintegrate $J/\Psi$. Fast pions accompanying parent nucleons would effectively increase the cross-section for inelastic nucleon-$J/\Psi$ collisions in the Gerschel-Hüfner picture.

The latter is the suppression of $J/\Psi$ by partons (mostly gluons) produced in semi-hard nucleon-nucleon sub-collisions. As argued in Ref.[11] and discussed below, the uncertainty principle leads to a relative suppression of soft
interactions in nucleon-nucleon sub-collisions in interactions of heavy ions at high energies. Secondary partons produced in one sub-collision interact with $J/\Psi$ produced in another sub-collision and this leads to additional $J/\Psi$ suppression.

The purpose of the present note is to study in some detail the latter mechanism, to estimate the corresponding $J/\Psi$ suppression and to find conditions under which this additional suppression gives a factor of about two in Pb-Pb collisions, and factor close to one in interactions of lighter ions.

Suppression of $J/\Psi$ by gluons has already been discussed by Wong [12] and by Xu et al. [13]. In contradistinction to Wong [12] we emphasize here that the time during which intermediate stage gluons exist prior to their hadronization increases with increasing gluon density and as a consequence of that also with increasing nucleon numbers of colliding nuclei. According to the view we are advocating here, this effect is responsible for the anomalous $J/\Psi$ suppression in Pb-Pb collisions as observed by NA-50 Collaboration [8].

Xu et al.[13] consider an equilibrating parton plasma which, starting from the original inequilibrium approaches thermal equilibrium. Such a process extends over the time of several fm/c and might correspond to what will happen in the RHIC and LHC energy range. In our model we assume that intermediate stage gluons are present in the system only during 0.5 - 1.5 fm/c and after that they hadronize without approaching an equilibrium in the partonic stage.

We also put emphasis on the relationship between this picture of $J/\Psi$ suppression and the enhanced production of strangeness in heavy- ion collisions.

The paper is organized as follows: In the next Section we shall briefly describe the picture of the space-time evolution of heavy- ion collision we are using [11]. In Sect.3 we study the time-evolution of density of semihard gluons. Sect.4 contains estimates of $J/\Psi$ suppression by this mechanism. Comments and conclusions are presented in Sect.5.
2 Parton model of heavy-ion collisions in the 200AGeV energy range

According to models [14] based on Perturbative Quantum Chromodynamics (PQCD) of proton-proton interactions at high energies the collision consists of two parts: a semi-hard parton - parton interaction (mostly gluon - gluon; in what follows we shall refer explicitly to gluons) populating the central rapidity region and fragmentation of ”wounded” nucleons [15] (less understood, because not described by PQCD). Models of semi-hard collisions introduce a cut-off on momenta of participating gluons $p_T > p_T^0$ in order to have finite cross-sections and not to enter the non-perturbative region. The value of $p_T^0$ depends somewhat on the energy of $pp$ collision and is in the region $0.5 GeV < p_T^0 < 1 GeV$ for lab. energies of a few hundred GeV. The existence of the cut-off may be connected with the screening of individual partons by other partons in the system.

The presence of two mechanisms of hadron production in $pp$ collisions is indicated by data on strange baryon production [16] where $\bar{\Lambda}$ seems to be produced by the harder mechanism populating the region $-0.3 < x_{cm} < 0.3$, whereas $\Lambda$ is produced by both mechanisms, the former being the semi-hard and the latter due to proton fragmentation. These two mechanisms are visible also from data on transverse momentum spectra of $\Lambda$ and $\bar{\Lambda}$. The harder mechanism is connected with larger transverse momenta and has a smaller $p_T$ -slope. The slope of $\Lambda$ production has a break in the slope parameter, corresponding to the transition from the softer to the harder dynamics. This break of the $p_T$ -slope of $\Lambda$-production has been observed also at lower energies of 12.4 GeV/c and 200 GeV/c [17] what indicates the presence of both mechanisms also at lower energies. The slope of $\bar{\Lambda}$ is smaller and about the same as the slope of $\Lambda$ at higher $p_T$. Similar findings on the spectra of $\Lambda$ and $\bar{\Lambda}$ has been reported also in the study of strange particle production at 360 GeV/c [18]. For a detailed review of data and references on strange particle production see Kachelhoffer and Geist [19].

These features of data lead us to conjecture that in nucleon-nucleon collisions at lab.energy of about 200 GeV, there are two mechanisms present:

(i) a harder one, probably due to semi-hard gluon- gluon interaction, populating central $x_{cm}$ region,

(ii) a softer one, presumably associated with nucleon fragmentation, pop-
ulating the beam and target proton fragmentation regions and extending partly to the central region. Near $x_{cm} \approx 0$, the contribution from (i) is presumably dominating as indicated by roughly equal magnitudes of cross-sections for $\Lambda$ and $\bar{\Lambda}$ at $x_{cm} \approx 0$ [14].

Data on $\Lambda$ and $\bar{\Lambda}$ production thus give evidence on the presence of the two mechanisms at $E_{lab} \approx 200\text{GeV}$ and indicate that semi-hard PQCD gluon-gluon interactions combined with fragmentation of wounded nucleons might provide a useful picture of what happens in first stages of both pp and nucleus- nucleus interactions in this energy range. Note that this picture does not contradict the work [20] on nuclear stopping power at $E_{lab} \approx 100\text{GeV}$ in the interpretation of Daté et al.[20].

In ion- ion interactions soft exchanges in nucleon- nucleon sub- collisions are suppressed by the uncertainty principle, the argument being similar to that of the Landau- Pomeranchuk mechanism, for a review see Ref.[21]. In heavy- ion collision each nucleon collides with a few nucleons from another ion. If time and longitudinal distance between two subsequent collisions are $\Delta t$ and $\Delta z$ the uncertainty principle mechanism suppresses processes with energy and longitudinal momentum transfer

$$\Delta p_z < \frac{\hbar}{\Delta z}, \quad \Delta E < \frac{\hbar}{\Delta t} \quad (1)$$

Mean free path for a nucleon passing through a nucleus at rest is about 3fm. When considering a collision of two ions at $E_{lab} \approx 200\text{ GeV}$, in the c.m.s. of nucleon -nucleon collision both nuclei are contracted by the Lorentz factor $\gamma \approx 10$, the mean free path becomes shorter by the factor $\gamma$ and Eq.(1) leads to a suppression of energy and momentum transfer with

$$\Delta p_z < 600\text{MeV}/c, \quad \Delta E < 600\text{MeV} \quad (2)$$

Just above these limits one is at the border of applicability of the notion of semi-hard collision between partons and accurate calculations are not very reliable. In spite of that, due to hints provided by data on $\Lambda$ and $\bar{\Lambda}$ production discussed above, we suppose that the picture based on semihard production of gluons (which hadronize later on) and fragmentation of nucleon remnants may provide a useful insight into the first stages of ion-ion collisions even in the energy range of $E_{lab} \approx 200\text{ AGeV}$. This picture is also relevant for the question of $J/\Psi$ suppression. Gluons produced in nucleon- nucleon sub-
collisions can collide with $J/\Psi$ and disintegrate it. According to Ref.[9] the inelastic $g + J/\Psi$ cross-section reaches its maximal value around 3mb for gluons with momentum of about 1GeV/c and this is what one expects for gluons originated in semi-hard interactions and $J/\Psi$ at rest in the c.m.s. of nucleon- nucleon system.

In the next Sect. we shall discuss the expected evolution of intermediate stage gluon densities in heavy-ion collisions.

3 Evolution of gluon densities in heavy-ion collisions in the 200 AGeV energy range

For the sake of simplicity we shall picture the colliding nuclei A and B as cylinders of lengths $2L_A$ and $2L_B$ and radii $r_A$ and $r_B$. These parameters are fixed for each nucleus by requiring that the volume of the cylinder and the volume of the sphere are the same and that the value of $<z^2>$ where $z$ is the distance from the centre of the sphere (from the centre of the cylinder) along the z-axis, identical with the axis of rotational symmetry for the cylinder. In this way we find

$$L_A = \sqrt{\frac{3}{5}} R_A, \quad r_A^2 = \frac{2}{3} \sqrt{\frac{5}{3}} R_A^2$$

(3)

Space-time evolution of two colliding rows of nucleons, each row consisting of a tube along the z-axis, can be visualized simply as shown in Fig.1, where one can see the position of both rows at any value of time. Taking a particular value of $z$ and making in that point straight line parallel to the t-axis we find the time interval during which nucleons of both rows collide at this value of $z$. The time when nucleons start to collide in point $z$ is denoted as $t_1(z)$ and the time when collisions cease as $t_2(z)$. The rate $(dn/dt)_0$ at which gluons are produced in the point $z$ vanishes for $t \leq t_1(z)$ as well as for $t \geq t_2(z)$. Within the time interval $t_1(z) < t < t_2(z)$ the rate is given as

$$\alpha \equiv (\frac{dn}{dt})_0 = v_{rel} \rho_0 \gamma \rho_0 \sigma 2C$$

(4)

where $v_{rel} \approx 2c$ is the relative velocity of colliding nucleons, $\sigma$ is the cross-section for semi-hard nucleon-nucleon collision leading to production of two
gluons with momenta larger than about 0.5GeV, $\rho_0$ is the nucleon density in a nucleus at rest and factor 2 stands for the production of two gluons in one sub-collision. The factor $C$ takes into account that partons which are responsible for most of semi-hard interactions are not Lorentz contracted. Positions of collisions within the nucleus $A$ will not be distributed within the distance $2L_A/\gamma$ but over a larger distance $(2L_A/\gamma + \Delta)$ where $\Delta$ is about 1fm. The correction factor $C$ thus becomes

$$C = \frac{R_A}{R_A + \delta} \frac{R_B}{R_B + \delta}$$

(5)

where

$$\delta = \frac{1}{2} \sqrt{\frac{5}{3}} \gamma \Delta \approx 6.5 \Delta$$

(6)

Note that this correction leads to rather lower densities for collisions of lighter ions. To get a feeling for the numbers, consider Pb-Pb collision with the following parameters: $v_{rel} \approx 2c$, $\gamma \approx 10$ (this corresponds to $E_{lab} \approx 200$ AGeV), $\sigma \approx 20mb = 2fm^2$, $\rho_0 \approx 0,15 fm^{-3}$, $\Delta \approx 1 fm$, $R_{Pb} \approx 7 fm$. The resulting $(dn/dt)_0$ becomes about $(4,8\text{gluons}) fm^{-3}(fm/c)^{-1}$. For an S-S collision due to the C-factor the corresponding $(dn/dt)_0$ is only about a half of the value for Pb-Pb.

By estimating $\sigma \approx 20mb$ we make the crucial assumption that a large part of nucleon- nucleon interaction in ion- ion collision is due to semi- hard interactions even at $E_{lab} \approx 200$ AGeV. For this assumption the role of principle of uncertainty, see Eqs.(1) and (2), is essential.

The second decisive parameter is the time $\tau$ which a gluon spends in the system as a gluon. This parameter can be estimated as follows. In proton-proton collision one can imagine that the two gluons separate, extend a colour string between themselves, the tension of the string being $1GeV/fm$, and after a time of about $0.5 fm/c$, when the energy of gluons is converted to that of the string tension, the hadronization starts. In a heavy-ion collision the situation might be rather different. The region in which nucleons collide contains coloured partons what screens interactions between gluons. Gluons produced in one of semi-hard interactions may interact with softer gluons of incoming nucleons what would increase their number. They can also interact with gluons originated by other semi-hard collisions what makes their lifetime longer. We shall lump all these effects into a single parameter $\tau$ and consider
its value as a free parameter with a value of about 0.5-1.5 fm/c, depending on the gluon density and on the size of the intermediate gluonic system.

We assume that the density of gluons increases due to semi-hard collisions in the region of nucleon-nucleon collisions shown in Fig.1 and that this density is decreasing due to the hadronization of gluons and their escape from this region. Characterizing the loss of gluons by a characteristic time \( \tau \) we can write the equation for the time evolution of gluon density in point \( z \) as:

\[
\frac{dn}{dt} = (\frac{dn}{dt})_0 - \lambda n, \quad \lambda = \frac{1}{\tau}
\]

with \( \alpha \equiv (dn/dt)_0 \) given by Eq.(4). The solution of Eq.(7) is

\[
n(t) = \tau \alpha [1 - e^{-\lambda(t-t_1)}]
\]

for

\[
t_1 \equiv t_1(z) \leq t \leq t_2 \equiv t_2(z)
\]

and

\[
n(t) = \tau \alpha [1 - e^{-\lambda(t_2-t_1)}] e^{-\bar{\lambda}(t-t_2)}, \quad t \geq t_2
\]

where \( \bar{\lambda} = 1/\bar{\tau} \) describes the rate at which gluons disappear after nucleons ceased to interact in the point \( z \). In making the estimates we shall first assume that \( \bar{\tau} = 0 \), what corresponds to \( n(t) = 0 \) for \( t > t_2 \). Note, however, that \( \bar{\tau} \) may become large when the density of gluons approaches or exceeds the critical density corresponding to the phase transition to QGP. We shall return to this point below.

The time dependence of gluon density as given by Eq.(8) has two simple limiting cases:

(i) The time \( \tau \) is small with respect to \( t_2 - t_1 \). In that situation the expression \( \lambda(t - t_2) \) is large for most of time \( t \) within \( (t_1, t_2) \) and we have a constant gluon density

\[
n(t) \approx \tau \alpha, \quad t_1 \leq t \leq t_2
\]

and

\[
n(t) = 0 \quad for \quad t \leq t_1, t \geq t_2
\]

This approximation overestimates the gluon density for values of \( z \) where \( t_2(z) - t_1(z) \) is smaller or roughly equal to \( \tau \) and underestimates the density for situations when \( t_2(z) - t_1(z) \) is larger than \( \tau \) or when \( t > t_2(z) \).
(ii) The time $\tau$ is large with respect to $t_2 - t_1$. In this case gluon density is increasing linearly with time

$$n(t) \approx \alpha(t - t_1), \quad t_1 \leq t \leq t_2$$

(11)

4 Suppression by intermediate stage gluons

When the time dependence of gluon density is known we can calculate the survival probability of $J/\Psi$ by standard procedures, see e.g. Ref.[4]. For $J/\Psi$ at rest in the c.m.s. of nucleon- nucleon collision the survival probability $S$ due to interactions with gluons is given as

$$S = \left\langle \exp\left( - \int <\sigma_d> n(t') v_{rel} dt' \right) \right\rangle$$

(12)

where $<\sigma_d>$ is the mean value of the cross-section for $J/\Psi$ disintegration in $g + J/\Psi$ collisions obtained by averaging over momenta of gluons. Most of gluons produced in semi-hard nucleon- nucleon collisions have momenta within the range $0.5 GeV/c \leq p \leq 1.5 GeV/c$. According to estimates of the disintegration cross- section for $g + J/\Psi$ collisions given by Kharzeev and Satz [9] we shall take $<\sigma_d> = 2 mb = 0.2 fm^2$. For massles gluons $v_{rel} = c$.

We shall now calculate the $J/\Psi$ survival probability, first by using the approximation in Eq.(10) and then by using the numerical solution of Eqs.(8,9). In the limiting case of Eq.(10) with constant gluon density, Eq.(12) simplifies to

$$S = \left\langle \exp\left( - \int a dt \right) \right\rangle, \quad a = <\sigma_d> \tau (dn/dt)_o c = \text{const.}$$

(13)

Averaging in Eq.(13) goes over all positions $(z,t)$ in which $J/\Psi$ can be created and the integral in Eq.(13) has as the lower limit the time $t_1(z)$ and as the upper limit $t_2(z)$ (when one assumes, as we now do, that the density of gluons vanishes for $t > t_2(z)$). The Eq.(13) can be then rewritten as

$$S = \frac{1}{P} \int dz \int dt e^{-a(t_2(z) - t_1(z))}$$

(14)

where one integrates over the region of nucleon- nucleon collisions shown in Fig.1. The ”surface” of this region is denoted as $P$. The integral in Eq.(14) can be explicitly performed and we find for Pb-Pb collision

$$S = \frac{2}{(aL)^2} [aL - 1 + e^{-aL}]$$

(15)
where \( L = 2L_{Pb}/\gamma + \Delta \) as discussed between Eqs.(4) and (5). Using Eq.(3) to calculate \( L_{Pb} \) with \( R_{Pb} \approx 7 \text{fm} \) and taking \( \Delta = 1 \text{fm} \) we find \( L \approx 2.2 \text{fm} \).

Value of \( a \) is determined by using Eq.(13) with the following parameters:
\[
< \sigma >_d = 2 \text{fm}^2, \tau = 0.5 \text{fm}/c, (dn/dt)_0 = 4.8 \text{fm}^{-4}c \text{ as estimated below Eq.(6).} \]
In this way we get \( a = 0.48 \text{fm}^{-1} \). For the product \( aL \) this leads to \( aL = 1.06 \). Inserting that into Eq.(15) we obtain

\[
S_{Pb-Pb}(\text{gluons}) = 0.71 \tag{16}
\]

Proceeding in the same way in the case of S-S collisions we get \( L = 1.6 \text{fm} \), \( a = 0.24 \text{fm}^{-1} \) and \( aL = 0.38 \). Inserting that into Eq.(15) leads to

\[
S_{S-S}(\text{gluons}) = 0.88 \tag{17}
\]

The results as given by Eqs(16) and (17) are not satisfactory, since the additional suppression given by intermediate stage gluons is only 0.71 for Pb-Pb interactions but it is as high as 0.88 for S-S interactions. The data would rather require about 0.5 for Pb-Pb and something closer to one for S-S collisions. Since some errors may be due to the approximation itself, we shall in what follows, use numerical results based on solutions given in Eqs.(8) and (9). Survival probability is calculated by Eq.(12). Some results are summarized in Table 1. As can be seen from the Table there is no combination of relaxation times \( \tau \) and \( \bar{\tau} \) which would give the required patterns of \( J/\Psi \) suppression for both S-S and Pb-Pb interactions.

The required patterns can be obtained provided that we assume that for a system like Pb-Pb where the dimensions and the gluon density are larger the relaxation time is also larger. This is certainly not very surprising since we expect that the relaxation of intermediate stage gluons has some similarity with a diffusion process and the coefficient of diffusion is proportional to the mean free path which decreases with decreasing density of particles.

As seen in Table 1 combinations with \( \tau \approx 0.5 \text{ fm}/c \) and \( \bar{\tau} \approx 1.5 \text{ fm}/c \) and \( \tau \approx 1 \text{ fm}/c \) and \( \bar{\tau} \approx 1 \text{ fm}/c \) give additional suppression of \( J/\Psi \) in Pb-Pb collisions of about 0.56. Combinations with \( \tau \approx 0.5 \text{ fm}/c \) and \( \bar{\tau} \approx 0.5 \text{ fm}/c \) keep \( J/\Psi \) suppression at acceptable levels of \( S(S-S) \approx 0.89 \) and \( S(S-Pb) \approx 0.83 \) in S-S and S-Pb collisions.
5 Comments and conclusions

The approach we have used in estimating the evolution of gluons produced in semi-hard nucleon-nucleon interactions is admittedly oversimplified, but it permits rough estimates of \(J/\Psi\) suppression by these gluons. The process itself is rather short and is followed by hadronization of gluons present in the intermediate stage. To get a better understanding of the process one should study the behaviour of the intermediate systems of gluons and find the dependence of basic parameters, in particular of \(\tau\) on the size of the system. Such a dependence is able to explain the abruptness of the decrease of survival probability of \(J/\Psi\) as observed by the NA-50 Collaboration. The model we have used above explains the abrupt increase of \(J/\Psi\) suppression by an increase of the relaxation time of intermediate stage gluons in Pb-Pb interactions. Gluons in the intermediate stage are not supposed to approach the equilibrium in the QGP stage and hadronize before such a state can be reached. The system of hadrons may thermalize depending on the density and size of the hadronic system.

In spite of the crudeness of approximations made above we shall now discuss what might be the relation of the system of gluons produced in semi-hard nucleon-nucleon collisions to QGP. The energy density \(\varepsilon_g\), of these intermediate stage gluons can be simply estimated as

\[
\varepsilon_g \approx \langle \varepsilon \rangle \tau (dn/dt)_0 \approx \langle \varepsilon \rangle > 2.4 \text{fm}^{-3}
\]

where \(\langle \varepsilon \rangle\) is the average energy of a semi-hard gluon.

Taking \(0.5 GeV \leq \langle \varepsilon \rangle \leq 1 GeV\) we obtain

\[
1.2 GeV \text{fm}^{-3} \leq \varepsilon_g \leq 2.4 GeV \text{fm}^{-3}
\]

According to lattice calculations [20] the critical temperature for the phase transition to QGP is between 150 MeV and 200 MeV, the lower values being preferred. The corresponding energy densities are

\[
0.8 GeV \text{fm}^{-3} \leq \varepsilon_{crit} \leq 2.5 GeV \text{fm}^{-3}
\]

The comparison of these two regions of energy density indicates that the effect observed by the NA-50 Collaboration [8] might be connected with the closeness of the energy density of semi-hard gluons to the critical one. In our
model it is natural to assume that the relaxation time of the gluonic system increases substantially when the density of gluons approaches the critical one. The abrupt increase of $J/\Psi$ suppression could mean that the NA-50 Collaboration have ”touched” the plasma and the experiments at RHIC and LHC will study the plasma in detail.

In analyses [3,4] of the early NA-38 data [2] one was looking for a ”kink” in the dependence of $J/\Psi$ survival on the energy density as estimated by the Bjorken formula (for a discussion along these lines see e.g. the second paper in Ref.[4]). Even without a deeper theoretical understanding a possible ”kink” has been considered to be a sign of a ”threshold” signalling a transition to a different dynamical regime of heavy-ion collisions. Increased accuracy of data has shown [5] that up to S-U collisions there were no kinks, also no thresholds and presumably also no transition. New phenomenon observed by the NA-50 Collaboration has all the features one can expect from a kink signalling a transition to a new dynamical regime.

The interpretation of results of NA-50 Collaboration as an indication of a transition to another dynamical regime are further corroborated by the recent data of NA-44 Collaboration at CERN-SPS [23] which give for the longitudinal radius $R_L$ as obtained from the study of Bose-Einstein correlations the value of about 6fm. This is much larger than the value found for S-Pb collisions [23,24,25]. Both phenomena deserve a careful and systematic analysis, including a study of possible alternative explanations. Only after having excluded such alternative possibilities one could draw stronger conclusions on the nature of the transition to a different dynamical regime in central Pb-Pb collisions. If the interpretation presented above has some contact with reality one can expect strong ”threshold effects” connected with some form of a kink also in the behaviour of other signatures and perhaps also in shifts of masses of some resonances [22,26].

The explanation of increased $J/\Psi$ suppression by increased life-time of the intermediate gluonic system is quite natural and in a sense trivial. What is non-trivial is the fact that the additional suppression can be obtained with expected values of cross-sections for both semi-hard gluon-gluon collisions and disintegration of $J/\Psi$ in a collision with a gluon. Non-trivial are also consequences of this picture for other signatures of QGP.

The understanding of what is going on in heavy-ion collisions will most likely come not from a single piece of data but rather via consistency of one picture with numerous types of experimental information. The picture
presented above leads to the following qualitative consequences. In contradis-
tinction to QGP followed by the mixed phase, the intermediate gluonic stage 
produces practically no photons and no dileptons, its contributions to the 
life- time and the size of longitudinal expansion are also smaller than those 
of equilibrated QGP. For photon and dilepton production and for the longi-
tudinal radius $R_L$ one expect in this picture essentially only the contribution 
from the thermalized hadron gas stage.

Strangeness is expected to be enhanced first by semi- hard gluon- gluon 
collisions which are flavour blind and have probably enough energy to produce 
more of heavier strange particles than softer fragmentation.

The initial conditions for the hydrodynamical evolution in this picture 
correspond more to the Landau scenario than to the Bjorken one.

The intermediate parton stage is present in numerous models of $e^+e^-$ 
and hadronic collisions [27,28]. Our picture of heavy- ion collisions goes in a 
similar way to systems with higher density of gluons.

The NA-50 data can be also described as $J/\Psi$ disintegration by comov-
ing hadrons [29]. The two picture might differ significantly in the question of 
strangeness enhancement, provided that the expansion of the hadronic sys-

tem is not long enough to establish the chemical equilibrium by collisions of 
secondary hadrons.

Blaizot and Ollitrault [30], see also Kharzeev [31], have explored a scenario 
in which all $J/\Psi$ are totally suppressed in regions where the energy density 
exceeds a critical value slightly greater than that attained in S+U collisions. 
Such a scenario indicates the formation of QGP and differs from the scenario 
with shorter stage of intermediate gluons by the expansion patterns.

In conclusion, we have suggested a picture of heavy- ion collisions in 
which secondary particles appear either from fragmentation of nucleon rem-
nants or from the evolution of intermediate system of gluons formed by semi-
hard gluon- gluon collisions. In this picture $J/\Psi$ is suppressed both by the 
Gerschel- H"ufner mechanism and by the intermediate system of gluons. The 
picture is able to describe the NA-50 data on Pb+Pb collisions provided that 
the life- time of the intermediate gluon stage is increasing with increasing nu-
cleon numbers of colliding ions and with increasing centrality of collision. For 
central Pb+Pb collisions the required life- time of the intermediate gluonic 
system is about 1.5 fm/c, and the corresponding density of gluons in these 
collisions is close to the critical one.

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Table 1: Table 1. The dependence of $J/\Psi$ survival probabilities on relaxation times $\tau$ and $\bar{\tau}$

| $\tau \,[fm/c]$ | $\bar{\tau} \,[fm/c]$ | $S(S+S)$ | $S(S+Pb)$ | $S(Pb+Pb)$ |
|-----------------|-----------------|-----------|------------|------------|
| 0.3             | 0.3             | 0.93      | 0.89       | 0.82       |
| 0.5             | 0.5             | 0.89      | 0.83       | 0.73       |
| 0.5             | 1.0             | 0.83      | 0.76       | 0.64       |
| 1.0             | 0.5             | 0.86      | 0.78       | 0.67       |
| 1.0             | 1.0             | 0.79      | 0.70       | 0.56       |
| 0.5             | 1.5             | 0.79      | 0.69       | 0.56       |
| 1.0             | 1.5             | 0.74      | 0.62       | 0.48       |
| 0.5             | 2.0             | 0.74      | 0.63       | 0.50       |
| 1.0             | 2.0             | 0.68      | 0.56       | 0.42       |
| 2.0             | 2.0             | 0.65      | 0.52       | 0.37       |

Additional survival provability due to intermediate stage gluons is calculated by using: Eqs.(8),(9) and (12) with $\sigma_g = 2 \, fm^2$ (gluon pair production in a nucleon - nucleon collision) and $\sigma_d = 0.2 \, fm^2$ (disintegration of $J/\Psi$ in collision with a gluon).

Figure Caption

Fig.1 The z-t diagram of the space-time evolution of nucleon- nucleon collision. Nucleons of two equal mass nuclei, modelled as cylinders, collide within the square indicated. At a particular value of z the nucleon- nucleon collisions start at $t=t_1(z)$ and end at $t=t_2(z)$. Length of each cylinder is $2L_A/\gamma + \delta$ and the symbols used are explained in the text.
References

[1] T. Matsui and H. Satz, Phys. Lett. B178 (1986) 416
[2] C. Baglin et al., Phys. Lett. B220 (1989) 471; C. Baglin et al., Phys. Lett. B255 (1991) 459; C. Baglin et al., Phys. Lett. B270 (1991) 105; C. Baglin et al., Phys. Lett. 345 (1995) 617
[3] A. Capella et al., Phys. Lett. B206 (1988) 354; J.-P. Blaizot and J.-Y. Ollitrault, Phys. Lett. B217 (1989) 386; S. Gavin, M. Gyulassy and A. Jackson, Phys. Lett. B207 (1988) 257; R. Vogt, M. Prakash, P. Koch and T. H. Hansson, Phys. Lett. B207 (1988) 263; R. Vogt, S. J. Brodsky and P. Hoyer, Nucl. Phys. B360 (1991) 67
[4] J. Ftáčník, P. Lichard and J. Pištúť, Phys. Lett. B207 (1988) 194; J. Ftáčník et al., Zeit. f. Phys. C42 (1989) 139
[5] C. Gerschel and J. Hufner, Phys. Lett. B207 (1988) 253; C. Gerschel and J. Hufner, Zeit. f. Phys. C56 (1992) 171; C. Gerschel, Nucl. Phys. A583 (1995) 643
[6] S. Katsanévas et al., Phys. Rev. 60 (1988) 2121
[7] D. M. Alde et al., Phys. Rev. Lett. 66 (1991) 2285
[8] P. Bordalo for NA-50 Collaboration, $J/\Psi$ suppression in Pb-Pb interactions at 158 GeV/nucleon, Talk at Rencontres de Moriond; M. Gonin, Talk at Quark Matter '96 Conference, May 1996, Heidelberg
[9] D. Kharzeev and H. Satz, Colour deconfinement and Quarkonium dissociation, CERN-TH/95-117, May 1995, To appear in Quark-Gluon Plasma II, R. C. Hwa (Ed.), World Scientific, Singapore; March, 1996; D. Kharzeev and H. Satz, Phys. Lett. B334 (1994) 155, D. Kharzeev, L. McLerran and H. Satz, Phys. Lett. B356 (1995) 349, D. Kharzeev and H. Satz, Phys. Lett. B356 (1995) 365, D. Kharzeev and H. Satz, Phys. Lett. B366 (1996) 316
[10] J. Pištúť, N. Pištúťová and P. Závada, Zeit. f. Phys. C67 (1995) 467
[11] R. Lietava, J. Pištúť, N. Pištúťová and P. Závada, Strangeness enhancement in proton-nucleus collisions in a parton model, Comenius University Bratislava, in preparation; J. Pištúť, talk at the WA-97 Meeting, January 1996, CERN
[12] C.-Y. Wong, Phys. Rev. Lett. 76 (1996) 196
[13] X.-M.Xu,D.Kharzeev,H.Satz and X.-N.Wang, $J/\Psi$ suppression in an equilibrating Parton Plasma, preprint CERN- TH/95 -304; hep- ph/9511331, Nov.1995

[14] T.Sjöstrand and M. van Zijl,Phys.Rev. D36 (1987) 2019; L.Durand and H. Pi, Phys. Rev. D40 (1989) 1436; N. Abou el Naga, K.Geiger and B.Müller, J.Phys.G G18 (1992) 797; M.Borzumati and G.Kramer, Zeit. f. Phys. C67 (1995) 137; G.A. Schuler and T.Sjöstrand, Phys.Rev. D49 (1994) 2257, M.M.Block et al., Phys. Rev. D45 (1992) 839

[15] A.Bialas et al.,Nucl.Phys. B111 (1976) 461; A.Bialas and W.Czyz, Nucl.Phys. B194 (1982) 21; A.Bialas et al., Phys. Rev. D25 (1982) 2328

[16] H.Kichimi et al., Phys.Rev. D20 (1979) 37

[17] J.W.Chapman et al., Phys.Lett. 47B (1973) 465; M.Alston- Garjost et al., Phys.Rev. Lett. 35 (1975) 142; K.Jae ger et al., Phys.Rev. D11 (1975) 1756 and 2405; A.Sheng et al., Phys.Rev. D11 (1975) 1733; P.Skubic et al., Phys. Rev. D18 (1978) 3115

[18] M.Asai et al., Zeit.f.Phys. C27 (1985) 11

[19] T.Kachelhoffer and W.Geist, Estimates of relative yields of strange baryons and antibaryons from pp and pA interactions, Strasbourg preprint CRN 96-03

[20] R.C.Hwa,Phys.Rev.Lett. 52 (1984) 493; J.Hüfner and A.Klar, Phys.Lett. B145 (1984) 167; K.Kinoshita et al., Progr. Theor. Phys. 63 (1980) 928; R.C.Hwa and M.Zahir, Phys.Rev. D31 (1985) 499; S.Date et al., Phys.Rev. D32 (1985) 619

[21] E.L.Feinberg and I.Ya.Pomeranchuk,Suppl. Nuovo Cim. 3 (1956) 652

[22] F.Karsch et al., Zeit.f.Phys. C60 (1993) 519; S.Gottlieb et al.,Phys.Rev. D35 (1987) 3972; R.V.Gavai et al., Phys.Lett. B241 (1990) 437

[23] J.Dodd,NA-44 Collaboration, Talk at the 25th International Symposium on Multiparticle Dynamics, Stará Lesná, 12th-16th Sept. 1995, to be published in the Proceedings; S.Slegt et al. WA-93 Collab., Nucl.Phys. A590 (1995) 469c

[24] T.Alber et al., NA-35 Collab., Zeit.f. Phys. C66 (1995) 77

[25] J.Pišút, N.Pišútová and P.Závada, Comenius University, Bratislava, in preparation
[26] H.Leutwyler and A.V.Smilga, Nucl.Phys. **B342** (1990) 437

[27] J.Ellis and K.Geiger, Phys.Rev. **D52** (1995) 1500; CERN-TH./95- 283 (1995) and hep-ph/ 9511321; CERN- TH./96- 105 and hep-ph/ 9605425

[28] B.R.Webber, Nucl.Phys. **B238** (1984) 492; G.Marchesini and B.R. Weber, Nucl.Phys. **B349** (1991) 617

[29] S.Gavin and R.Vogt, Charmonium suppression by comover scattering in Pb+Pb collisions, preprint LBL- 37980, (1996); S. Gavin et al., Zeit. f. Phys. **C61** (1994) 351; S.Gavin and R.Vogt, Transverse momentum of Ψ and dimuon in Pb+Pb collisions, preprint CU- TP- 791

[30] J.-P.Blaizot and J.- Y. Ollitrault, Phys. Rev. Lett. **77** (1996) 1703

[31] D.Kharzeev, Talk at Quark Matter Conference, Heidelberg, May, 1996, hep- ph/ 9609025
$$t_1(z)$$

$$t_2(z)$$

Fig. 1