GCP Code Applied in $J/\psi$ Production and Absorption

Xiao-Xia Yao$^{a,b}$, Wei-Qin Chao$^{a,b}$ and Yang Pang$^c$

$^a$ CCAST (World Laboratory), Beijing, 100080, P.R. China
$^b$ Institute of High Energy Physics, Academia Sinica, P.O.Box 918-4, 100039, P.R.China
$^c$ Phys Dept. Columbia Univ., New York, USA

Abstract

Using the General Cascade Program (GCP), the production and absorption of $J/\psi$ in p-A and A-A collisions have been studied. Nucleon absorption mechanism and comover absorption mechanism are considered to investigate the $J/\psi$ suppression. The results agree well with experimental data of $J/\psi$ production, except for the data in Pb-Pb collision.

PACS number(s): 24.10.Lx, 25.75.Dw, 12.38.Mh

Keyword: $J/\psi$ suppression; GCP; nucleon absorption of $J/\psi$; comover
I. Introduction

Suppression of $J/\psi$ production in high energy heavy ion collisions was proposed as a promising signature for the formation of quark gluon plasma (QGP) by Matsui and Satz ten years ago [1]. This suppression effect was observed by NA38 collaboration later [2]. However, it has been found that $J/\psi$ suppression exists also in p-A collisions where QGP formation is not possible [3]. Since then, the source of the observed $J/\psi$ suppression has remained controversial. Recently the NA50 collaboration reported the anomalous $J/\psi$ suppression in Pb-Pb collision [4,5]. Now the debate has focussed on whether or not the data can be consistently described by hadronic mechanisms [6–10]. So it is important to study first the $J/\psi$ suppression caused by hadronic mechanisms.

There are several sources of $J/\psi$ suppression in hadronic matter. Such as the absorption of $J/\psi$ in nuclear matter, the interaction of $J/\psi$ with the produced mesons (called comover), gluon shadowing in nuclei, energy degradation of produced $J/\psi$. In this paper, we will discuss the effects of the first two hadronic mechanisms on $J/\psi$ suppression.

General Cascade Program (GCP) [11] is designed by Y. Pang. It is a Monte Carlo simulation code based on cascade method. Cascade method has been used extensively in studying relativistic heavy ion collisions. It is perhaps the only quantitative tool currently available which is capable to provide both the overall features and the specific properties of nucleus-nucleus collisions at extremely high energies.

In principle, the cascade algorithm itself is rather simple. One could visualize most cascades as collisions of classical billiard balls traveling at relativistic speed. Most cascade codes, on the other hand, are often quite complex. This is because each code must include a large number of physical processes in order to generate a realistic nucleus-nucleus collision event. Additional assumptions is often required in order to simulate an actual nucleus-nucleus collision. There are also parameters introduced during the cascade. The final result of a cascade often depends on these assumptions and parameters. The physical processes in these models can be quite different. For most cascade based models, it is often difficult to extract the key physics ingredient without having to go over the entire source code. It is not easy to compare various models, even when good agreements between the model predictions and the experimental data in the observed spectra have
been reached.

GCP is designed such that the cascade algorithm is separate from the complexities of physics models. So the problem of the cascade can be isolated and studied separately, and different physics models can be compared in a common framework. GCP itself is only a cascade model, a tool for building relativistic cascade models including various physical contents. This is the key difference between GCP and most other cascade codes.

By now there are many discussion on $J/\psi$ suppression. However, only a few works started to treat the Monte Carlo simulation of $J/\psi$ production and absorption directly \cite{12,13}. While \cite{12} claimed that the $J/\psi$ suppressions in p-A and A-A collisions, including Pb-Pb data, could be explained based on nucleon and comover absorption, ref \cite{13} showed that it is impossible to fit the abnormal $J/\psi$ suppression in Pb-Pb collision only based on hadronic absorptions. Besides, the influence of the lifetime of the wounded nucleon is not investigated in details before. This is the reason why we use the code GCP to study $J/\psi$ suppression. We intend to study the influence of the lifetime of wounded nucleon on the strength of comover absorption. Our results show that it is not possible to fit the Pb-Pb data within reasonable choices of parameters. Our work is divided into two parts. First, the longitudinally excited wounded nucleon model(LEWM) is added to GCP. We use it to handle the nucleus-nucleus interaction. Next, the process of $J/\psi$ production and absorption in p-A and A-A collisions in SPS energy is simulated using GCP. The results agree well with most experiment data of $J/\psi$ production in p-A and A-A collisions, except for the data in Pb-Pb collision, where the hadronic absorption mechanisms failed to follow the abnormally strong $J/\psi$ suppression.

The outline of the paper is as follows: In section II, we describe the transport approach and cascade method. In section III, the nucleus-nucleus interaction in GCP is described. In section IV, the nucleon and comover absorption mechanisms for $J/\psi$ suppression is investigated. In the last section, some further discussions are given.

II. Transport approach and cascade method

In a many body system, if correlation between particles is weak, i.e. independent particle pictures is a good approximation, and if the interaction is dominated by short-
range forces, we may treat the system as a collection of point particles propagating freely between successive short-range interactions. This system can be described by a set of Boltzmann equations, which can be solved using the cascade algorithm [13].

In the absence of interactions, particles travel on straight line trajectories, and the equation for the time evolution of $\omega_a$ is

$$p^\mu \partial_\mu \omega_a(x, t, \vec{p}) = 0. \quad (1)$$

$\omega_a$ is the probability density of finding an on-shell particle $a$, with momentum $\vec{p}$, at position $x^\mu = (\vec{x}, t)$. Considering the interaction between particles, an $S$–matrix is included to determine the interaction going from the initial state $|b_1, b_2, \cdots, b_n >$ to the final state $|c_1, c_2, \cdots, c_m >$,

$$< c_1, c_2, \cdots, c_m | S | b_1, b_2, \cdots, b_n > = A_{n \rightarrow m} (2\pi)^4 \delta^4\left(\sum_{i=1}^n p_{b_i} - \sum_{j=1}^m p_{c_j}\right). \quad (2)$$

Summing over all possible incoming channels and outgoing channels, we get a very general transport equation, with local interactions, in the absence of mean fields,

$$p^\mu \partial_\mu \omega_a(x, t, \vec{p}) = \sum_{b_1, b_2, \cdots, b_n} \int \prod_{i=1}^n \frac{d^3 \vec{p}_{b_i}}{(2\pi)^3 2E_{b_i}} \omega_{b_i}(\vec{x}, t, \vec{p}_{b_i}) \left( \sum_{c_1, c_2, \cdots, c_m} \int \prod_{j=1}^m \frac{d^3 \vec{p}_{c_j}}{(2\pi)^3 2E_{c_j}} |A_{n \rightarrow m}|^2 \right)$$

$$\sum_{b_1, b_2, \cdots, b_n} \sum_{c_1, c_2, \cdots, c_m} \int \prod_{i=1}^n \frac{d^3 \vec{p}_{b_i}}{(2\pi)^3 2E_{b_i}} \omega_{b_i}(\vec{x}, t, \vec{p}_{b_i}) \left( \sum_{c_1, c_2, \cdots, c_m} \int \prod_{j=1}^m \frac{d^3 \vec{p}_{c_j}}{(2\pi)^3 2E_{c_j}} |A_{n \rightarrow m}|^2 \right)$$

$$\left(2\pi\right)^4 \delta^4\left(\sum_{i=1}^n p_{b_i} - \sum_{j=1}^m p_{c_j}\right)$$

$$\left[- \sum_{i=1}^n \delta_{ab_i} \delta^3(\vec{p} - \vec{p}_{b_i}) 2E_{b_i} + \sum_{j=1}^m \delta_{ac_j} \delta^3(\vec{p} - \vec{p}_{c_j}) 2E_{c_j}\right], \quad (3)$$

where ‘−’ and ‘+’ in the fourth line before $\delta$ functions represent the decrease of particles of type $a$ from the incoming channels and the increase of $a$ in the outgoing channels, respectively. In principle, given the initial values of the distribution and all $A_{n \rightarrow m}$’s, Equation(3) can be solved.

A particle cascade is one of the best method for solving these equations. In a cascade, the probability distributions $\omega_a$ of particle $a$ are sampled by $M_a$ test points,

$$\omega_a(\vec{x}, t, \vec{p}) = \frac{N_a}{M_a} \sum_{i=1}^{M_a} \delta^3(\vec{x} - \vec{x}_i(t)) \delta^3(\vec{p} - \vec{p}_i), \quad (4)$$
where $N_a$ is the total number of $a$. In the limit $M_a \to \infty$, $\omega_a$ can be described accurately by the density of test points. In the collision free limit,

$$\omega_a(x, t, p) = \frac{N_a}{M_a} \sum_{i=1}^{M_a} \delta^3(x - x_i(0) - v_i(t)) \delta^3(p - p_i)$$

is a solution to Eq.(1), where $v_i = \frac{p_i}{E_i}$. Between collisions particles travel along a straight line, as in Eq.(5).

For the case of resonance decay ($n=1$),

$$\frac{1}{2E_b} \int \prod_{j=1}^{m} \frac{d^3 \vec{p}_{c_j}}{(2\pi)^{3}2E_{c_j}} |A_{1 \to m}|^2 \delta^4(p_b - \sum_{k=1}^{m} p_{c_k}) = \eta_{b \to c_1 + c_2 + \cdots + c_m}. \quad (6)$$

$\eta_{b \to c_1 + c_2 + \cdots + c_m}$ represents the decay rate for the channel of $b \to c_1 + c_2 + \cdots + c_m$. The total decay rate is $\eta_b = \sum_{m} \sum_{c_1, c_2, \cdots, c_m} \eta_{b \to c_1 + c_2 + \cdots + c_m}$. One can convert the decay rate to the resonance lifetime, $\eta_b = \frac{1}{(\gamma_b \tau_b)}$, where $\gamma_b = \frac{|\vec{v}_2 - \vec{v}_1|}{E_b}$ is the Lorentz decay factor, $\tau_b$ is the inherent lifetime of resonance state $b$.

In two body collisions ($n = 2$),

$$\frac{1}{2E_{b_1} \cdot 2E_{b_2}} \int \prod_{j=1}^{m} \frac{d^3 \vec{p}_{c_j}}{(2\pi)^{3}2E_{c_j}} |A_{2 \to m}|^2 \delta^4(p_{b_1} + p_{b_2} - \sum_{k=1}^{m} p_{c_k}) = |\vec{v}_2 - \vec{v}_1| \sigma_{b_1+b_2 \to c_1 + c_2 + \cdots + c_m}, \quad (7)$$

where $\sigma_{b_1+b_2 \to c_1 + c_2 + \cdots + c_m}$ is the partial cross-section for the channel of $b_1 + b_2 \to c_1 + c_2 + \cdots + c_m$. The total cross-section is found by summing over all outgoing channels,

$$\sigma_{b_1+b_2} = \sum_{m} \sum_{c_1, c_2, \cdots, c_m} \sigma_{b_1+b_2 \to c_1 + c_2 + \cdots + c_m}. \quad (8)$$

The product $|\vec{v}_2 - \vec{v}_1| \cdot \sigma_{b_1+b_2}$ is a cylindrical volume with a length $|\vec{v}_2 - \vec{v}_1|$ and a cross-section $\sigma_{b_1+b_2}$. It represents the probability of collision between particles $b_1$ and $b_2$ in a unit time. We can simulate this term by making a collision between a point particle
$b_1$ and a point particle $b_2$ whenever they are approaching each other within a cross-section $\sigma_{b_1+b_2}$. We can set the collision time to be the time when the distance between the two particles is at a minimum. When a collision occurs, the partial cross-sections are used to determine the branching ratio to a particular channel.

The momentum distribution for the outgoing particles are selected within the phase space, weighted by $|A_{n\rightarrow m}|^2$, and constrained by the energy momentum conservation [16],

$$
\int \prod_{j=1}^{m} \frac{d^3\vec{p}_c}{(2\pi)^3 2E_c} |A_{n\rightarrow m}|^2
(2\pi)^4 \delta^4(\sum_{l=1}^{n} p_{b_l} - \sum_{k=1}^{m} p_{c_k}).
$$

(9)

The cascade reduces the solution of the transport equations into the scattering of a set of classical point particles with known cross-sections and branching ratios. However, there is one problem unsolved. Although the transport equation is local and Lorentz invariant, the cascade breaks this invariance by allowing particles to collide at a distance $d = \sqrt{\sigma/\pi}$ apart (for $n = 2$). The collisions are time ordered and this ordering is frame dependent. Therefore, Lorentz invariant is not strictly satisfied. The codes based on cascade method generally have this problem. The result of Monte Carlo simulation depends on the selection of frame more or less. At present energy range, the results of different frames consistent with each other qualitatively. However, the problem will be more serious at RHIC energy region. In ref. [11] a method is proposed to recover this invariance.

### III. The nucleus-nucleus interaction in GCP

In building the interaction of GCP, it is convenient and instructive to build up the physics step by step.

1. Nucleon-nucleon interaction

In GCP, the processes of the resonance production, $\pi$ production and the resonance decay are included in nucleon-nucleon interaction table,

$$
N + N \longrightarrow N^* + N^*,
$$

(10)

$$
N + N \longrightarrow N + N + l\pi,
$$

(11)
\( N^* \rightarrow N + \pi, \quad (12) \)

where \( l \) is the number of produced \( \pi \), which is related to the energy in the center of mass frame. The probability of the interactions is determined by the branching ratios. In GCP, the difference between proton(p) and neutron(n) is not considered. \( \pi^+, \pi^-, \pi^0 \) are also regarded the same as \( \pi \).

(1). The process of \( \pi \) production

According to the experimental results, the average number of produced charged particles in N-N collisions can be expressed as [17]

\[
<N_{ch}> = 0.88 + 0.44\ln s + 0.118(\ln s)^2, \quad (13)
\]

where \( s \) is the square of the energy in the center of mass frame, in unit GeV\(^2\). Since the difference of \( \pi^+, \pi^- \) and \( \pi^0 \) is neglected, after removing the contribution of leading particles, we can get the average multiplicity of pions

\[
<n> = \left[ <N_{ch}> - 1.5 \right] \times \frac{3}{2}. \quad (14)
\]

Introducing the selected multiplicity distribution, one can use GCP to get the multiplicity \( n \) for each collision. The energy and momentum conservation are constrained during the collision processes. No other dynamics mechanism is included in GCP. In GCP, we choose \( P_t \)-limited phase space distribution. Considering the leading particle effect of incoming nucleon, uniform longitudinal momentum distribution of pions is selected. We put KNO distribution into GCP and get the multiplicity distribution of pions which is shown in fig.1. The statistical results of the rapidity distribution and the transverse momentum distribution of the produced particles in N-N collisions is shown in fig.2.

(2). The process of resonance decay

\( N^* \) is a resonance state which is produced during N-N interaction. In GCP, \( N^* \) will decay to \( N \) and \( \pi \) within a given time \( \tau \), which is shown in Eq.(12).

2. p-A and A-A collision

The description that \( \pi \) is produced immediately after each N-N collision in p-A and A-A collisions is not actually the case. The longitudinally excited wounded nucleon model(LEWWM) is introduced in GCP. In LEWWM, each N-N collision leads to two
longitudinally excited clusters. The clusters decay after a certain time. The decay of clusters is the source of other produced particles in N-N collision.

In LEWNM the nucleons are not transversely excited but only longitudinally stretched after the N-N collision. The collision of a beam nucleon and a target nucleon will result in two excited clusters, 'string1' and 'string2':

\[ N + N \rightarrow string_1 + string_2. \]  \hspace{1cm} (15)

The mass of the clusters are fixed in the following way: By using GCP, the process of \( \pi \) production in N-N collisions is simulated. In the center of mass frame, the particles are divided into two clusters according to their \( z \) direction. The invariant masses of all particles in each of the two clusters are counted over a broad range of c.m. energies of the N-N system. Then we can get the empirical formula of the mass of the cluster which is a function of the c.m. energy of the N-N system.

The longitudinally excited clusters 'string1' and 'string2' subsequently decay,

\[ string \rightarrow N + l\pi. \]  \hspace{1cm} (16)

If the resonance or string collide with other particles before decaying new excited clusters may produce. Decay of the clusters are the source of particle production.

The secondary collisions are also considered in p-A and A-A collision. The processes mainly include:

\[ N(N^*, string) + \pi \rightarrow N + \pi + l\pi, \]  \hspace{1cm} (17)

\[ \pi + \pi \rightarrow \pi + \pi + l\pi. \]  \hspace{1cm} (18)

The process of N-N collision is not changed after introducing the LEWNM into GCP. According to the experimental condition, we also have simulated the S-U collision. The statistical results of transverse energy \( (E_T) \) distribution are shown in figure 3. The LEWNM gives a good description of many observable quantities in N-N, p-A and A-A collisions.

It can be applied to the study of relativistic nucleus-nucleus reactions.

3. Collision geometry
The nuclear geometry plays an important role in relativistic heavy ion collisions. The overlapping area of the two colliding nuclei is determined by the impact parameter $b$. We call the nucleons in the overlapping area the participants. The number of participants is calculated according to the nuclear geometry. Considering the change of $b$, we get the distribution of the number of participants. The larger the $b$, the less the number of participants. In GCP, $b$ is an input parameter. It can be fixed or selected randomly in a certain region.

In section II, we have discussed that the collision is possible when the distance of closest approach of the two colliding particles is less than the interaction range $d$, related to the total cross-section by $d = \sqrt{\sigma/\pi}$. The possible future collisions are ordered in time and form the collision list. The next collision is the earliest one on the list.

So the basic considerations of GCP only relate to collision geometry and cascade simulation, no other dynamics of the production process is included. The aspects we mentioned above are only related to the nuclear geometry and kinematics. The detailed physical assumptions can be introduced according to the physical models. This is the remarkable advantage of GCP.

IV. The hardronic mechanisms on $J/\psi$ suppression

Two hardronic mechanisms of $J/\psi$ suppression are added to GCP to simulate the production and absorption of $J/\psi$.

1. The process of $J/\psi$ production and absorption

The channels for $J/\psi$ production and absorption are added to GCP to simulate the process of $J/\psi$ production and absorption:

$$N(N^*, \text{string}) + N(N^*, \text{string}) \rightarrow N + N + J/\psi$$  \hfill (19)

$$N(N^*, \text{string}) + J/\psi \rightarrow N + D + \bar{D}$$  \hfill (20)

$$\pi + J/\psi \rightarrow D + \bar{D}$$  \hfill (21)
Since the probability of $J/\psi$ production in N-N collision is relatively small, the cross-section of $J/\psi$ production is enlarged in the simulation to increase $J/\psi$ production probability. In general, one or two $J/\psi$ are produced in each event in the simulation.

2. The mechanism of the $J/\psi$ absorption in nuclear matter

Based on above discussions, one can accept the following physical picture that the $J/\psi$ production can be divided into two steps. The first step is the production of a $c\bar{c}$ pair, which is produced perturbatively and almost instantaneously. The second step is the formation of a physical state of $J/\psi$, that needs a much longer time. In a nucleus-nucleus collision, $c\bar{c}$ are produced by hard scattering processes of beam nucleon and one target nucleon. The produced $c\bar{c}$ may interact with another target nucleon and these $c\bar{c}$-nucleon interactions may lead to the break up of $c\bar{c}$ via the reaction

$$c\bar{c} + N(N^*, \text{string}) \rightarrow D + \bar{D} + x,$$

which turns $c\bar{c}$ into $D\bar{D}$ pair. Thus, $c\bar{c}$-nucleon interactions will give a suppression of $J/\psi$ production.

3. The mechanism of the interaction between $J/\psi$ and produced mesons

Comovers usually refer to the secondaries produced in high energy heavy ion collisions, such as $\pi, \rho$ and $\omega$ mesons, etc. In A-A collisions, besides $J/\psi$-nucleon absorption, $J/\psi$ particles also suffer interaction with secondaries that happen to travel along with them, which also causes $J/\psi$ suppression. The reaction is shown in Eq. (21).

The details of simulating the process of $J/\psi$ production and absorption are as following:

(1). An entry for $J/\psi$ production is added to the interaction table. We use average impact parameter $<b>$ to discuss minimum biased data. For the situation of different $E_T$ bin the values of b are given by experimental groups [2] [3]. In order to increase the probability of $J/\psi$ production, we enlarge the cross-section of $J/\psi$ production to ensure one or two $J/\psi$ produced in every event. Running GCP, we get statistical number of $J/\psi$, $N_{pro}$, in 10000 events.

(2). Put the channel for $J/\psi$-nucleon interaction into GCP. Using the same condition as (1), we run GCP again to count the number of $J/\psi$, $N_{abs(N)}$, in 10000 events, where the nucleon absorption is included.
At last, $J/\psi$-comover interaction is added to GCP. Using the same condition as (1), we obtain the number of $J/\psi$, $N_{abs(N+co)}$, after considering the nucleon and comover absorption.

The $J/\psi$ survival probability in A-B collision is expressed as

$$S = \frac{N_{abs}}{N_{pro}}. \quad (23)$$

The absorption cross sections of $J/\psi$, i.e. the cross-sections that the produced $J/\psi$ particles interact with target nucleons or produced secondary particles, are important parameters to explain the $J/\psi$ suppression in hardronic environment. There are two parameters, $J/\psi$-nucleon cross-section $\sigma_{abs(N)}$ and $J/\psi$-comover cross-section $\sigma_{abs(co)}$. After analyzing many sets of experimental data in p-A collisions, Gerchel and H"{u}fner [15] found that the experimental $J/\psi$ production data for p-A collisions can be fitted well with an effective $J/\psi$-nucleon cross section $\sigma = 6.2mb$ or $6.9mb$. To account for the A-A data, $J/\psi$-comover absorption cross-section is generally regarded as about $3mb$. In GCP, $\sigma_{abs(N)}$ and $\sigma_{abs(co)}$ are input parameters. We wish to adjust the parameters to agree well with the experimental data of $J/\psi$ suppression.

First we discuss the case of minimum biased data. Considering only the absorption of $J/\psi$ by nucleus, the GCP simulation of $J/\psi$ survival probabilities at SPS energy are expressed as squares in fig.4. The experimental data are shown as black triangles. The $J/\psi$-nucleon cross-section is taken to be $\sigma_{abs(N)} = 7mb$, which is in good agreement to earlier works [13]. The lifetime of the wounded nucleon is taken to be 1fm/c. One can see clearly that our simulation is in good agreement with the experiment data of $J/\psi$ production in p-A collisions. Most of the $J/\psi$ suppression data for A-A collisions are also fitted, but one can not explain the data in Pb-Pb collision. Using GCP, we can simulate the $J/\psi$ production and absorption in p-A and A-A collisions up to S-U data successfully. Next, $J/\psi$-comover interaction is added to GCP. Considering the nucleon and comover absorptions of $J/\psi$, we repeat the above procedure again. The value of $\sigma_{abs(N)}$ is taken the same as above. The $J/\psi$-comover absorption cross-section is $\sigma_{abs(co)} = 2mb$. The results are expressed as open triangles in fig.4. It shows that the $J/\psi$-comover interaction in A-A collisions is more important than that in p-A collisions. However, to include the comover absorption has not introduced qualitative difference from the result including only nucleon
absorption. The combination of these two absorption mechanisms of $J/\psi$ still cannot explain the data for Pb-Pb collision. In the above situation, the lifetime of the wounded nucleon is taken as $1\text{fm/c}$. In GCP, the decay of the wounded nucleons is the source of particle production. If their lifetime decreases, other particles such as mesons will be produced earlier. This may increase the probability of $J/\psi$-comover interaction. Fig.5 shows the results in p-A and A-A collisions obtained using the lifetime of the wounded nucleons as $0.2\text{fm/c}$. It can be seen from the result that the shorter lifetime does provide a much stronger comover absorption. Now the Pb-Pb data can be reached. However the other fitting points are much lower than the experimental data in lighter A-A collisions. The above analysis tells us that one cannot explain the $J/\psi$ suppression for all the observed experimental data consistently based on the one set of parameters. Then we adjust $\sigma_{abs(N)}$ to $6\text{mb}$, $\sigma_{abs(co)}$ to $3\text{mb}$, repeat the above step again. In this case, the comover absorption of $J/\psi$ is more manifest. But the overall results are similar to fig.4.

Now we turn to discuss the result of different $E_T$ bins. In the same way as above, we simulate the two kinds of $J/\psi$ suppression, the interaction of $J/\psi$ with nuclear matter and produced meson in S-U and Pb-Pb collisions. For different $E_T$ bins, the values of $b$ are given by experimental groups, which are listed in table 1. The parameters $\sigma_{abs(N)}$ and $\sigma_{abs(co)}$ used in considering the $J/\psi$-nucleon absorption and $J/\psi$-comover absorption and the lifetime of the wounded nucleon are taken to be the same as those used for fig.4. in fitting the minimum biased data. The squares in fig.6 show that $J/\psi$ suppression in S-U collision could be described very well based on our nucleon absorption. However, the fitting for the last $E_T$-bin in Pb-Pb collision using only nucleon absorption shows that (the most right square in fig.6) the data in Pb-Pb collision could not be fitted using the same set of parameters. The interaction of $J/\psi$ with produced mesons make further suppression of $J/\psi$ in S-U and Pb-Pb collisions, which are shown as triangles. But the combination of these two kinds of absorption (see “▽” in fig.6) still cannot explain the extra strong $J/\psi$ suppression in Pb-Pb collision. There may be anomalous suppression caused by other mechanisms, e.g. QGP formation.

V. Results and Discussions
GCP is designed such that the cascade algorithm is separated from the physics models. In this way the problem of the cascade can be isolated and studied separately, and different physics models can be compared in a common framework. GCP itself is only a tool to simulate the cascade process. The various physics models can be built based on it. This is the key difference between GCP and most other cascade codes.

In this paper, we focus our attention on the Monte Carlo simulation of $J/\psi$ production and absorption directly by using GCP. Our work is divided into two parts. First, the longitudinally excited wounded nucleon model (LEWNM) is added to GCP. It is used to handle the nucleus-nucleus interaction. The LEWNM is found to give a good description of many observables in N-N and p-A collisions, such as the multiplicity distributions, the rapidity distributions, and the transverse momentum distributions of the produced particles. According to the experimental conditions, we have also simulated the transverse energy distribution for S-U collision. Next, two hardronic mechanisms of $J/\psi$ suppression, $J/\psi$-nucleon interaction and $J/\psi$-comover interaction, are added into GCP to simulate the production and absorption of $J/\psi$ in p-A and A-A collisions at SPS energy. First we consider the case of minimal biased data. Then the results of different $E_T$ bins are discussed. Using the nucleon absorption mechanism, the results agree well with the experimental data of $J/\psi$ production, except for those in Pb-Pb collision. Based on above discussion, the comover absorption mechanism is added to GCP to study the suppression of $J/\psi$ production. The $J/\psi$ suppression in Pb-Pb collision can not be explained even by the combination of the above two mechanisms. It seems that some new mechanisms is needed to study the anomalous $J/\psi$ suppression in Pb-Pb collision. This may indicate the formation of QGP.

Acknowledgments

This work is supported in part by the National Natural Science Foundation of China and Natural Science Foundation of Hebei province. We would like to thank Zhang X.F. and Tai A. for stimulating and helpful discussions.
REFERENCES

[1] T. Matsui and H. Satz, Phys.Lett. B178 (1986) 416; T. Matsui, Z.Phys. C38(1988)245.

[2] The NA38 Collaboration, Z.Phys. C38(1988)17; Phys.Lett.B220(1988)471; B255(1991)255; Nucl.Phys. A544(1992)209c.

[3] C. Morel et al., Phys. Lett. B 252 (1990) 505; D. M. Aldel et al. Phys. Rev. Lett. 66 (1991) 133.

[4] M. Gonin et al. (NA50), Report at Quark Matter 1996, Heidelberg, Germany;

[5] F. Fleuret (NA50 Collab.), in Proceedings of the 32nd Rencontres de Moriond, QCD and High Energy Hadronic Interactions, Les Arcs, France, 1997.

[6] D. Kharzeev, invited talk at QM’97.

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

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

[9] A. Tai, W. Q. Chao and X. X. Yao, hep-ph/9701207.

[10] D. Kharzeev and H. Satz, Phys. Lett. B366 (1996) 316. D. Kharzeev, C. Lourenco, M. Nardi and H. Satz, hep-ph/9612217.

[11] Y. Pang, in Proceedings of CCAST Symposium/Workshop on Particle Physics at Fermi Scale, Beijing, May 1993, Edited by Y. Pang, J. Qiu and Z. Qiu (Gordon Breach, New York, 1993), p451. Ion Collisions.

[12] Cassing W, Bratkovskaya EL. Nucl.Phys.A623(1997)570; N.Armesto, A.Capella, hep-ph/9705275.

[13] B.H.Sai, A. Tai, nucl-th/9803033.

[14] Y. Pang, RHIC Summer Study ’96: Theory Workshop on Relativistic Heavy Ion Collisions July 8-19, 1996 at Brookhaven National Laboratory, edited by D.E.Kahana and Y.Pang, p193.
[15] C. Gerchel and J. Hübner, Phys. Lett. B207, 253(1988); C. Gerchel and J. Hübner, Nucl. Phys. A544, 513c(1992).

[16] Y. Pang, Lorentz Invariant Multiparticle Phase Space Based on ARC Experience.

[17] Cheuk-Yin Wong, Introduction to High Energy Heavy Ion Collisions, world scientific, printed in Singapore.
**Figure Caption**

Fig.1: the statistical results of the multiplicity distribution of pions in N-N collision.

Fig.2: the statistical results of the rapidity distribution and the transverse momentum distribution of the produced particles in N-N collision.

Fig.3: the statistical results of the transverse energy distribution of the produced particles in S-U collision.

Fig.4: The $J/\psi$ survival probability in p-A and A-A collisions obtained using the lifetime of the wounded nucleon as 1fm/c, together with minimum biased experimental data for (from left to right) p-Cu, p-W, p-U, O-Cu, O-U, S-U and Pb-Pb collisions.

Fig.5: The same as Fig.4 using the lifetime of wounded nucleon as 0.2fm/c.

Fig.6: The $J/\psi$ survival probability for different $E_T$ bins together with experimental data in S-U and Pb-Pb collisions.

**Table Caption**

Table I. The value of $<b>$ for different $E_T$ bins in A-A collisions.
Table I

|        | bin1 | bin2 | bin3 | bin4 | bin5 |
|--------|------|------|------|------|------|
| A-A    |      |      |      |      |      |
| S-U    |      |      |      |      |      |
|        | **E_T** | 34   | 58   | 88   | 120  | 147  |
|        | < b(E_T) > | 7.2  | 5.5  | 4.4  | 3.6  | 2.4  |
| Pb-Pb  |      |      |      |      |      |
|        | **E_T** | 25   | 42   | 57   | 71   | 82   |
|        | < b(E_T) > | 8.3  | 6.8  | 5.0  | 3.3  | 1.8  |
our results with only nucleon absorption

our results with nucleon and comover absorption

fig. 4
our results with only nucleon absorption

our results with nucleon and comover absorption

fig.5
our results with only nucleon absorption

our results with nucleon and comover absorption (S-U)

our results with nucleon and comover absorption (Pb-Pb)