Transverse energy dependence of J/Psi suppression in Au+Au collisions at RHIC energy

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Prediction for transverse energy dependence of J/ψ to Drell-Yan ratio in Au+Au collisions at RHIC energy was obtained in a model which assume 100% absorption of J/ψ above a threshold density. The threshold density was obtained by fitting the NA50 data on J/ψ suppression in Pb+Pb collisions at SPS energy. At RHIC energy, hard processes may be important. Prediction of J/ψ suppression with and without hard processes were obtained. With hard processes included, J/ψ’s are strongly suppressed.

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In relativistic heavy ion collisions J/ψ suppression has been recognized as an important tool to identify the possible phase transition to quark-gluon plasma. Because of the large mass of the charm quarks, cc pairs are produced on a short time scale. Their tight binding also make them immune to final state interactions. Their evolution probes the state of matter in the early stage of the collision. Matsui and Satz [1] predicted that in presence of quark-gluon plasma (QGP), binding of cc pairs into J/ψ meson will be hindered, leading to the so called J/ψ suppression in heavy ion collisions [1]. Over the years several groups have measured the J/ψ yield in heavy ion collisions (for a review of the data and the interpretations see [2,3]). In brief, experimental data do show suppression. However this could be attributed to the conventional nuclear absorption, also present in pA collisions.

The latest data obtained by the NA50 collaboration [4] on J/ψ production in Pb+Pb collisions at 158 A GeV is the first indication of anomalous mechanism of charmonium suppression, which goes beyond the conventional suppression in nuclear environment. The ratio of J/ψ yield to that of Drell-Yan pairs decreases faster with E_T in the most central collisions than in the less central ones. It has been suggested that the resulting pattern can be understood in a deconfinement scenario in terms of successive melting of charmonium bound states [5].

In a recent paper Blaizot et al [6] showed that the data can be understood as an effect of transverse energy fluctuations in central heavy ion collisions. Introducing a factor $\varepsilon = E_T/E_T(b)$ and assuming that the suppression is 100% above a threshold density (a parameter in the model) and smearing the threshold density (at the expense of another parameter) best fit to the data was obtained. Capella et al [7] analysed the data in the co-mover approach. There also, the co mover density has to be modified by the factor $\varepsilon$. Introduction of this ad-hoc factor $\varepsilon$ can be justified in a model based on excited nucleons represented by strings [8].

At a fixed impact parameter, the transverse energy as well as the number of NN collisions fluctuate. The fluctuations in the number of NN collisions were not taken into account in the calculations of Blaizot et al [6] or in the calculations of Capella et al [7]. We have analysed the NA50 data, extending the model of Blaizot et al [6] to include the fluctuations in number of NN collisions at fixed impact parameter. The E_T distribution was obtained in the geometric model, which includes these fluctuations. It was shown that with a single parameter, the threshold density, above which the J/ψ suppression is assumed to be 100%, good fit to the data can be obtained. In the present paper, we have applied the model to predict the E_T dependence of J/ψ to Drell-Yan ratio at RHIC energy. With RHIC being operational, it is hoped that the prediction will help to plan experiments to detect QGP. In the following, we will present in brief the model. The details can be found in [8].

In fig.1a, the experimental data along with the fit are shown. Parametric values of $\alpha$ and $\beta$ describe that average $E_T$ produced in individual NN collisions is $\beta/\alpha \sim 0.1GeV$. This is to be contrasted with the average $E_T \sim 1GeV$ produced in other AA collisions [10].

As mentioned in the beginning, we have assumed that above a threshold density n_c, the charmonium suppression is 100% effective [8]. Charmonium production cross-section at impact parameter b is written as,

$$d^2\sigma^{J/\psi}/db = \sigma^{J/\psi} \int d^2 s T_A^{eff}(s) T_B^{eff}(s-b) S(b,s)$$

(1)

where $T_A^{eff}$ is the effective nuclear thickness function,

$$T^{eff}(s) = \int_{-\infty}^{\infty} dz \rho(s,z) \exp(-\sigma_{abs} \int_z^{\infty} dz' \rho(s,z'))$$

(2)

with $\sigma_{abs}$ as the cross-section for J/ψ absorption by nucleons. The exponential factor is the nuclear absorption
survival probability, the probability for the $c\bar{c}$ pair to avoid nuclear absorption and form a $J/\psi$. $S(b,s)$ is the anomalous part of the suppression. Blaizot et al [4] assumed that $J/\psi$ suppression is 100% effective above a threshold density ($n_c$), a parameter in the model. Accordingly the anomalous suppression part was written as,

$$S(b,s) = \Theta(n_c - \epsilon n_p(b,s))$$ \hspace{1cm} (3)

where $n_p$ is the density of participant nucleons in the impact parameter space,

$$n_p(b,s) = T_A(s)[1 - e^{-\sigma_{NN}T_B(b,s)}] + T_A \leftrightarrow T_B$$ \hspace{1cm} (4)

and $\epsilon = E_T/E_T(b) = E_T/n_b/\alpha$ is the modification factor which takes into account the transverse energy fluctuations at fixed impact parameter [4]. This modification makes sense only when $n_p$ is assumed to be proportional to the energy density. Implicitly it was also assumed that the $E_T$ fluctuations are strongly correlated in different rapidity gaps. The assumption was essential as NA50 collaboration measured $E_T$ in the 1.1-2.3 pseudorapidity window while the $J/\psi$’s were measured in the rapidity window $2.82 < y < 3.92$ [4]. Strong correlation between $E_T$ fluctuations in different rapidity windows is explained in the Geometric model [8].

We calculate the $J/\psi$ production as a function of transverse energy, at an impact parameter $b$ as,

$$d\sigma^{J/\psi}/dE_T = \sum_{n=1}^{\infty} P_n(b,E_T)d^2\sigma^{J/\psi}/d^2b$$ \hspace{1cm} (5)

where $P_n(b,E_T)$ is the probability to obtain $E_T$ in $n$ NN collisions, expression for which can be found in [8].

The Drell-Yan production was calculated similarly, replacing charmonium cross section in eq(4) by the Drell-Yan cross-section,

$$d^2\sigma^{DY}/d^2b = \sigma^{DY} \int d^2s T_A(s)T_B(s-b)$$ \hspace{1cm} (6)

In fig.1b, we have compared the theoretical charmonium production cross-section with NA50 experimental data. The normalization factor $\sigma^{J/\psi}/\sigma^{DY}$ was taken to be 53.5. The solid curve is obtained with $\sigma_{abs}=6.4$ mb, and $n_c = 3.89$ fm$^{-2}$. Very good description of the data from 40 GeV onward is obtained. The model reproduced the 2nd drop around 100 GeV, (the knee of the $E_T$ distribution). It may be noted that if the fluctuations in the NN collisions were neglected, equivalent description is obtained with threshold density $n_c = 3.75$ fm$^2$, with smearing of the $\Theta$ function at the expense of another parameter. It is evident that in this model, the smearing is done by fluctuating NN collisions. Theoretical calculations predict more suppressions below 40 GeV, a feature evident in other models also. It is possible to fit the entire $E_T$ range, reducing the $J/\psi$-nucleon absorption cross-section. Recent data [11] on the $J/\psi$ cross section in $pA$ collisions point to a smaller value of $\sigma_{abs}$ ~ 4 to 5 mb. The dashed line in fig.1b, corresponds to $\sigma_{abs}=4$ mb and $n_c = 3.42$ fm$^{-2}$. However, it may be mentioned that $\sigma_{abs}=4$ mb does not allow a good fit to the $pA$ and S-U data [4].

FIG. 1. (a) Transverse energy distribution in Pb+Pb collisions, (b) $J/\psi$ to Drell Yan ratio in Pb+Pb collisions as a function of transverse energy.

Present model can be used to predict $E_T$ dependence of $J/\psi$ to Drell-Yan ratio at RHIC energy. Recent PHOBOS experiment [13] showed that for central collisions, total multiplicity is larger by 70% at RHIC than at SPS. We assume that $E_T$ is correspondingly increased [15]. Accordingly, we rescale the $E_T$ distribution for Pb+Pb collisions and assume that it represent the experimental $E_T$ distribution for Au+Au collisions at RHIC (small mass difference between Au and Pb is neglected). At RHIC energy the so-called hard component which is proportional to number of binary collisions appear. Model dependent calculations indicate that the hard component grows from 22% to 37% as the energy changes from $\sqrt{s}=56$ GeV to 130 GeV [14]. However we choose to ignore the hard component in $E_T$-distribution. The multiplicity distribution obtained by the PHOBOS collaboration, in the rapidity range $3 < |\eta| < 4.5$ could be fitted well with or without this hard component. Indeed, it appears that the data are better fitted without the hard component [14]. Global distribution e.g. multiplicity or transverse energy distributions are not sensitive to the hard component. In fig.2a, filled circles represent the “experimental” $E_T$ distribution for Au+Au collisions at RHIC, obtained by scaling the $E_T$ distribution in Pb+Pb collisions at SPS. The solid line is a fit to the
"experimental" $E_T$-distribution in the geometric model, obtained with $\alpha=3.09$ and $\beta=0.495$. Nucleon-nucleon inelastic cross section ($\sigma_{NN}$) was assumed to be 41 mb at RHIC, instead of 32 mb at SPS \cite{14}. Fitted values of $\alpha$ and $\beta$ are interesting. With these values average $E_T$ produced in individual NN collisions at RHIC is $\beta/\alpha=0.16$ GeV. This is to be compared with the value 0.1 GeV for Pb+Pb collisions at SPS. Average $E_T$ produced in individual NN collisions at RHIC is increased by 60%, compared to SPS energy. The apparent inconsistency is resolved if we remember that $\sigma_{NN}$ is increased by 30% from SPS to RHIC energy.

$$n_p^{hard}(b,s) = \sigma_{NN} T_A(s) T_B(b-s)$$

with $n_p^{hard}(b,s) = \sigma_{NN} T_A(s) T_B(b-s)$. With hard component, transverse density is increased, as a result, anomalous suppression will set in at lower $E_T$.

In fig.2b, we have presented the $J/\psi$ to Drell-Yan ratio obtained in the present model for Au+Au collision at RHIC energy. We have presented the results for the two sets of parameters: (A) $\sigma_{abs}=6.4$ mb, $n_c=3.8$ fm$^{-2}$ and (B) $\sigma_{abs}=4$ mb, $n_c=3.44$ fm$^{-2}$. The solid lines are the prediction for $J/\psi$ suppression neglecting the hard component in the transverse density, for the two sets of parameters (A) and (B) respectively. The dotted lines are the prediction including the hard component. We find that without the hard component, $J/\psi$ suppression at RHIC is similar to that obtained at SPS energy. The 2nd drop which occurred at 100 GeV in Pb+Pb collisions at SPS energy, now sets in around 180 GeV (knee of the $E_T$ distribution being around that energy). As mentioned earlier, at RHIC, $E_T(b)$ is increased, and without the hard component the transverse density is nearly same as it was in Pb+PB collisions at SPS. Anomalous suppression then occurs at larger $E_T$. As it was for Pb+Pb collisions at SPS, the two sets give nearly same suppression for $E_T$ beyond 100 GeV. It is also an indication that anomalous suppression occur at larger $E_T$.

If the transverse density is modified to include the hard component, $J/\psi$'s are strongly suppressed. In fig.2b, the dotted lines presents the results obtained with 37% hard component. Nearly same suppression is obtained for set A and B. At knee, suppression is 6 times greater than corresponding suppression without the hard scattering component. Very strong suppression wash out the 2nd drop, which was clearly visible at SPS, or in the prediction without the hard component. With hard component, as mentioned earlier, transverse density is increased and anomalous suppression sets in earlier. Blaizot et al \cite{13} also predicted the $E_T$ dependence of the $J/\psi$ suppression. In fig.2b, their result is shown (the dashed line). As mentioned earlier, fluctuations in number of NN collisions at fixed impact parameter was neglected. Also the model for $E_T$ production was not microscopic. However, at large $E_T$, our prediction agrees closely with theirs.

To summarize, prediction for $J/\psi$ suppression in Au+Au collisions at RHIC energy was obtained in a model which assume 100% absorption of $J/\psi$ above a threshold density. Transverse energy fluctuations as well as fluctuations in the number of NN collisions at fixed impact parameter were taken into account. The threshold density was obtained from the analysis of NA50 data on $J/\psi$ suppression in Pb+Pb collisions at SPS energy. At RHIC energy hard processes are important. Prediction of $J/\psi$ suppression, with and without the hard processes differ considerably. Without hard processes, predicted $J/\psi$ suppression at RHIC energy is similar to that obtained at SPS energy. The 2nd drop which occur at $E_T \sim$ 100 GeV at SPS energy moves upward to 180 GeV. Inclusion of hard processes modifies the transverse density resulting in considerable larger suppression. Very large suppression washes out the 2nd drop, which was visible.
at SPS energy or in the prediction without the hard processes.

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