

Geometric parametrization of J/ψ absorption in heavy ion collisions

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We calculate the survival probability of J/ψ particles in various colliding systems using a Glauber model. An analysis of recent data has reported a J/ψ -nucleon breakup cross section of 6.2 ± 0.7 mb derived from an exponential fit to the ratio of J/ψ to Drell-Yan yields as a function of a simple, linearly averaged mean path length $\langle L \rangle$ through the nuclear medium. Our calculations indicate that, due to the nature of the calculation, this approach yields an apparent breakup cross section which is systematically lower than the actual value. [S0556-2813(99)07405-1]

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I. INTRODUCTION

Recently, data from the NA50 Collaboration on J/ψ yields from $p+A$ and $A+A$ collisions have become available, which have been interpreted as displaying “anomalous J/ψ suppression” [1]. It has been predicted that in the case of a phase transition to a quark-gluon plasma (QGP), the yield of J/ψ is suppressed due to Debye screening [2]. There have been numerous efforts to explain these data, invoking such effects as interactions with comoving hadrons [3] and suppressed production due to initial state energy loss [4,5], as well as decreased yields in a QGP [6].

However, even in the absence of a deconfinement transition, a $c\bar{c}$ pair can undergo inelastic interactions as it traverses the nuclear medium, as has been shown recently in data from $p+A$ collisions [7]. Since the $c\bar{c}$ pair could eventually form a J/ψ , the loss of these pairs through absorption reduces the overall J/ψ yield. Thus, the signature for a deconfinement transition would be J/ψ suppression at a level beyond that expected from the normal nuclear medium, an effect referred to as “anomalous J/ψ suppression” [1].

In the analysis of the NA50 data, the ratio of observed J/ψ to Drell-Yan yields is interpreted as proportional to the J/ψ survival probability. This ratio is then fit as an exponential function of a simple, linearly averaged mean path length through the nuclear medium $\langle L \rangle$ which returns a value for the J/ψ -nucleon breakup cross section of 6.2 ± 0.7 mb [8]. The comparison of this experimentally determined cross section and theoretical modeling is important in determining the relative contributions of the “preresonance” color octet and the color singlet states [9–12] to the overall absorption in $A-A$ collisions, as well as in estimating the magnitude of the anomalous J/ψ suppression.

In this paper we describe a calculation of J/ψ survival probability in $A+A$ collisions. The results of this calculation indicate that a breakup cross section derived in the manner of [1] is systematically lower than the actual value. We will discuss the origin of this discrepancy.

II. GEOMETRIC MODEL

In order to study the effect of collision geometry on the J/ψ survival probability, we have utilized a Glauber model

approach, implementing Woods-Saxon parametrizations of nucleon distributions within the colliding nuclei. Thus, assuming spherical symmetry for the nuclei, the nucleon density is described by

$$\frac{dN}{dR} \propto \left[1 + \exp\left(\frac{R-C}{D}\right) \right]^{-1}, \quad (1)$$

where

$$C = R_0 \times A_{\text{nucleus}}^{1/3}, \quad (2)$$

where $R_0 = 1.11$ fm, A_{nucleus} is the mass number of the nucleus, and $D = 0.75$ fm. For the specific case of a Pb nucleus, the parameters used are $C = 6.624$ fm and $D = 0.549$ fm, as given in [13]. The nucleon-nucleon cross section used in the Glauber calculation is $\sigma_{\text{int}} = 30$ mb. The results of the calculation are not sensitive to the exact value of this parameter over the range 25–40 mb.

Production of J/ψ is modeled by assuming that each nucleon-nucleon collision has the same probability of producing a J/ψ . We note that this modeling assumes that initial state energy loss does not affect J/ψ production. We are currently investigating the validity of this condition; the results of this study will be addressed in detail in a follow-up paper [5].

After production, the J/ψ is taken to be at rest in the center-of-mass frame, such that the survival probability is a function of the path length through nuclear material which the J/ψ must traverse, the nucleon density, and the breakup cross section $\sigma_{J/\psi-N}$. Specifically, the survival probability calculation requires an integration over z :

$$P_{\text{surv}}^{\text{tgt,proj}} = \int_{z_{\text{production}}}^{z_{\text{tgt,proj}}} \exp[-\rho(R)\sigma_{J/\psi-N}z] dz, \quad (3)$$

where $z_{\text{tgt,proj}}$ is the position of the trailing edge of the target and projectile nuclei, respectively (defined by the z value, at the same x and y values as the production point, where the nucleon density is negligibly small), and $\rho(R)$ is the local

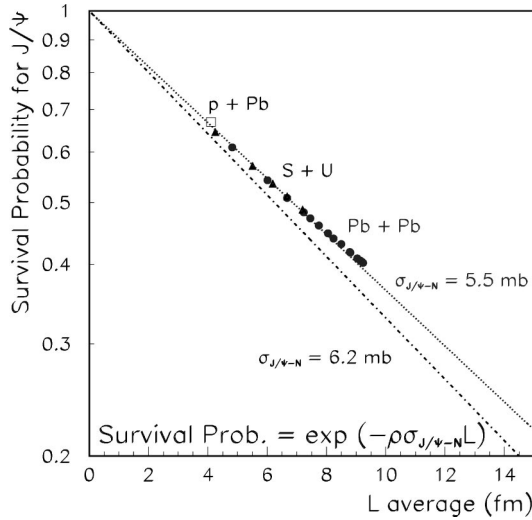


FIG. 1. Simulated J/ψ survival probability as a function of $\langle L \rangle$, the mean path length through the nuclear medium, for various colliding systems ($p+Pb$ are open squares, $S+U$ are solid triangles, and $Pb+Pb$ are solid circles—see the text for details on the values of $\langle L \rangle$). The points were generated using a breakup cross section of 6.2 mb in the nuclear medium. A fit to the calculated survival probabilities, shown as a dotted line, returns an effective absorption cross section of 5.5 mb. For comparison, the dashed line indicates the trend the points should take if $\langle L \rangle$ were a valid indicator of the mean free path in the nuclear medium.

nucleon density. The total survival probability is just the product of the two terms, $P_{\text{surv}} = P_{\text{surv}}^{\text{tgt}} \times P_{\text{surv}}^{\text{proj}}$.

Clearly, the survival probability of a given J/ψ depends strongly on where in the interaction region it is produced. However, for any given collision geometry (i.e., impact parameter), there is a wide range of possible production points, each with a different J/ψ survival probability. Thus, the mean survival probability for a given geometry represents an average over all possible J/ψ production points within the interaction region. We note that in the interpretation of actual experimental data, the situation is further complicated by the impossibility of experimentally selecting an impact parameter, given finite detector resolution and the natural dispersion in the various centrality related measurable quantities. Thus, measured J/ψ yields represent an average over various collision geometries in addition to the average over survival probabilities for a fixed, “ideal” geometry, as discussed here.

In previous analyses [1], the J/ψ survival probability was taken as proportional to the ratio of the observed yields of J/ψ to Drell-Yan. For various classes of event geometries, this ratio was fit as an exponential function of $\langle L \rangle$, the mean path length through the nuclear medium which the J/ψ must traverse. In that approach, $\langle L \rangle$ for a given class of geometries was the average of $\bar{L}(b)$ for the impact parameters b contained in that class and

$$\bar{L}(b) = \frac{1}{\rho_0} \left\langle \int \rho dz \right\rangle, \quad (4)$$

where ρ_0 is the mean nucleon density, ρ is the local nucleon density, and the integration is performed over the interaction region. We have performed a similar calculation within our

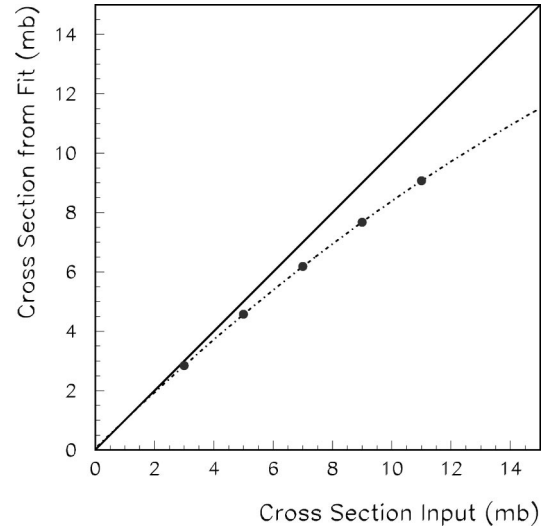


FIG. 2. Breakup cross sections as determined by an exponential fit of J/ψ yields as a function of $\langle L \rangle$, compared to the actual breakup cross sections used in the calculation. The values returned from the fit, shown as solid circles for several input values of the breakup cross section, are consistently lower than the actual input values (for comparison, a solid line of unit slope is also shown).

Glauber model. In our model, we have used a mean nuclear density of $\rho_0 = 0.1793$ nucleons/fm³; the results of the calculation are insensitive to this normalization factor. For a given collision system, the value $\langle L \rangle$ averaged over all impact parameters (i.e., minimum bias) can be calculated analytically (see [1] for details), which provides a cross-check of the $\langle L \rangle$ calculation; our values agree well with the expected values.

Shown in Fig. 1 are the calculated J/ψ survival probabilities for various colliding systems and geometries, plotted as a function of $\langle L \rangle$. To arrive at the specific $\langle L \rangle$ points given in the figure, we have simulated NA50 transverse energy bins [8]; transverse energy is assumed to scale as the number of wounded nucleons [14]. However, the substance of the figure does not depend on the specific centrality bins chosen. For the points shown, a breakup cross section of $\sigma_{J/\psi-N} = 6.2$ mb is used as input to our Glauber calculation. As can be seen clearly in Fig. 1, the apparent breakup cross section of 5.5 mb obtained from an exponential fit versus $\langle L \rangle$ differs substantially from the actual breakup cross section. Further, the points from the calculation, while they give a reasonable fit, do not lie precisely on an exponential. Since the points do not lie on a perfect exponential, the amount of error incurred by fitting as a function of $\langle L \rangle$ will depend on the exact centrality binning implemented. However, we emphasize that the discrepancy between the apparent and actual breakup cross sections is inherent in the collision geometry, and would be present even if it were possible experimentally to precisely determine the event impact parameter.

It is important to gauge the level of the deviation from exponential simply due to the error in calculating $\langle L \rangle$, since the anomalous suppression in $Pb+Pb$ collisions is measured relative to an extrapolation of the exponential fit. We have found that there is a systematic deviation from exponential, but of a relatively small magnitude. And it is notable that this deviation for the most central $Pb+Pb$ values is above the

projected exponential fit, in the opposite direction of the suppression. Thus the observed suppression is not explained away by the error in plotting versus $\langle L \rangle$.

However, the breakup cross section calculated this way is incorrect, and this error is straightforward to understand. For any single J/ψ , the survival probability follows an exponential in L for its given production point. However, when calculating the mean survival probability, care must be taken on how the mean path length is calculated. While the calculation of $\langle L \rangle$ as described above treats all points in the interaction region as contributing equally to production, it does not take into account the fact that, due to the exponential nature of absorption, all points in the interaction region do not contribute equally to net J/ψ yields. In order to accurately determine the actual breakup cross section from measured J/ψ yields, the possible production points must be weighted by their survival probability, which depends on the breakup cross section; thus, a proper calculation of $\sigma_{J/\psi-N}$ could be accomplished via an iterative calculation, similar in spirit to the one detailed here, which exactly returns the input cross section if a weighted mean path length is used. Since surviving J/ψ particles preferentially come from near the outer edges of the interaction region, an exponential fit versus a linearly averaged $\langle L \rangle$ systematically returns an appar-

ent breakup cross section which is less than the actual value. In Fig. 2, apparent breakup cross sections for various sample input breakup cross sections are shown; a fit to the points yields

$$\sigma_{\text{actual}} = 0.118 + 0.932\sigma_{\text{apparent}} + 0.030\sigma_{\text{apparent}}^2 \quad (5)$$

The exact values for this fit correspond to the centrality bins chosen, and vary slightly for different binning. With this caveat in mind, for an apparent breakup cross section of 6.2 ± 0.7 mb, as reported in [8], our model indicates that the actual breakup cross section is 7.1 ± 0.9 mb.

III. CONCLUSIONS

We have calculated the survival probability of J/ψ particles in various colliding systems using a Glauber model, and compared the results to the nuclear absorption observed by the NA50 collaboration [1]. While our calculation does not reconcile the issue of whether anomalous J/ψ suppression has been observed in the NA50 Pb+Pb data, it does indicate that the apparent breakup cross sections determined by a fit of yields versus $\langle L \rangle$ are systematically lower than the actual value, and a proper evaluation of the breakup cross section requires an iterative calculation.

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