

# Re-assessing the anomalous $J/\psi$ -suppression in the CERN NA50 data

Rajiv V. Gai<sup>a,b,1</sup>

<sup>a</sup>*Theoretical Physics Department, Tata Institute of Fundamental Research,  
Homi Bhabha Road, Mumbai 400005, India*

<sup>b</sup>*Center for Computational Physics, University of Tsukuba,  
Tsukuba, Ibaraki 305-8577, Japan*

## Abstract

A systematic analysis of the  $L$ -dependence of the  $J/\psi$ -suppression in the data of the CERN NA38 and NA50 experiments shows that the anomalous suppression in the 1995  $Pb-Pb$  data is at best a  $4\sigma$  effect at any of the  $L$ -values for the  $Pb-Pb$  data, where  $L$  is the geometrical mean path length of the  $J/\psi$  in the colliding nuclei. Possible implications for the 1996 data are discussed.

---

<sup>1</sup>E-mail:gai@tifr.res.in

Discovery of Quark-Gluon Plasma (QGP) is one of the most exciting aims of the current heavy ion collision experiments for a variety of reasons. Unfortunately, however, the evaporation of QGP is expected to occur in such a short time that establishing its formation by distinguishing possible hadronic backgrounds to the proposed signals of QGP is a very non-trivial task. Observation of  $J/\psi$ -suppression[1] has been thought of as a particularly promising way of looking for QGP. Here too, however, nuclear structure function effects[2] and absorption<sup>2</sup> of produced  $J/\psi$ 's by the surrounding nucleons[4] or the co-movers[5] are additional competing mechanisms.

The recent announcement[6] by the CERN NA50 experiment of observing once again anomalous  $J/\psi$ -suppression in their more precise 1996 data assumes a lot of significance in view of their earlier published results[7, 8] where they obtained anomalous suppression at about  $5\sigma$  level in the total  $J/\psi$  cross section in Lead-Lead collisions at 158 GeV/A and at about  $10\sigma$  level in the  $L$ -dependence of the suppression at their largest  $L$ -values. Here  $L$  is the geometrical mean path length of  $J/\psi$  in the colliding nuclei. It is obtained from the measured transverse energy  $E_T$  through its relation with the impact parameter  $b$  by performing a weighted average over possible production points of  $J/\psi$ . Proton-nucleus data and nucleus-nucleus data for light projectiles provides the standard in both the cases with respect to which the anomalous suppression is measured. As pointed out earlier[9], there are various theoretical uncertainties in this way of estimating the anomalous suppression. These range from simple propagation of errors due to the fitting procedure used to parameterize the usual suppression to the more intricate uncertainties in scaling some observed cross sections to energies other than the measured. Ref. [9] has evaluated many of these uncertainties for the anomalous suppression in the total cross sections and concluded that there was no anomalous suppression at 95 % confidence level, i.e. it was a less than a  $2\sigma$  effect. The experimental effect is claimed to be a lot stronger in the  $L$ -dependence of the suppression. In this brief note, we re-assess its statistical significance and find that the anomalous suppression at any given  $L$  is at most a  $4\sigma$  effect. We also update the results of Ref. [9] in view of the changes in the published[8] 1995 data of NA50 compared to their preliminary results[7].

In its data analysis[8], the NA50 collaboration fits the the (rescaled)  $pA$  data and  $A'A$  data to a power-law

$$B\sigma(\mathcal{A}) = \sigma_0 \mathcal{A}^\alpha \quad , \quad (1)$$

where  $B$  is the branching ratio for  $J/\psi \rightarrow \mu^+\mu^-$ , and  $\mathcal{A}$  is the effective mass number, given by the product of the mass numbers of the (light) projectile,  $A'$ , and target  $A$ . The  $L$ -dependence of the ratio  $R_{\text{expt.}}$  of the  $J/\psi$  cross section to the Drell-Yan cross section is, on the other hand, fitted by

$$R_{\text{expt.}} = C \exp(-\rho_0 \sigma_{\text{abs}} L) \quad , \quad (2)$$

where  $C$  is a constant,  $\rho_0 = 0.17 \text{ fm}^{-3}$  is the nuclear matter density and  $\sigma_{\text{abs}}$  is the absorption cross section for the  $J/\psi$  in nuclear matter. By taking logarithms of both

---

<sup>2</sup> It has been argued[3] that the usual color singlet  $J/\psi$  has too small absorption cross section and it is the color octet pre-resonant  $c\bar{c}$  which contributes to this mechanism. We will not need to worry here about such a distinction.

equations, the fits can be thought of as straight line fits. However, the NA50 data has measurement errors on *both*  $L$  as well as the ratio  $R_{\text{expt.}}$ ; the former come from binning of events in transverse energy. As a consequence, a straightforward least squares fit is inadequate in this case, unlike equation (1). One, therefore, has[10] to minimize the  $\chi^2$ , defined by

$$\chi^2(a, b) = \sum_{i=1}^N \frac{(y_i - a - bx_i)^2}{\sigma_{yi}^2 + b^2 \sigma_{xi}^2} , \quad (3)$$

where  $y(x) = a + bx$  is a straight line fit to a data set of  $N$  points  $(x_i, y_i)$ ,  $i=1, N$ , with  $\sigma_{xi}$  and  $\sigma_{yi}$  as the standard deviations in the  $x$  and  $y$  directions respectively.

The usual statistical procedure[11] to propagate errors is the following. Let us assume that the expectation values of a set of variables,  $p_i$ , are known along with their full covariance matrix,  $c_{ij}$ . Since we deal here with an  $f(p_i)$  which is a linear function of the  $p_i$ ,  $\langle f(p_i) \rangle = f(\langle p_i \rangle)$ , and the error

$$(\Delta f)^2 = \sum_{ij} c_{ij} \frac{\partial f}{\partial p_i} \frac{\partial f}{\partial p_j} . \quad (4)$$

Note that when the correlations vanish, this reduces to the usual formula for adding errors in quadrature. Obtaining the covariance of  $a$  and  $b$  in a linear fit is simple but it could be numerically tricky in the case of  $\chi^2$ -minimization for equation (3). One can overcome this by a simple observation<sup>3</sup>. Making a transformation  $x' = x + x_0$ , changes the intercept from  $a$  to  $a' = a + bx_0$ . Thus getting an error estimate on the parameter  $a'$  for the shifted data set under this transformation is the same as obtaining the  $\Delta y(x_0)$  including the full covariance matrix. We use this method to obtain  $\Delta y$  at each point  $x_0$  by defining it as usual as the variation in  $a'$  which produces a change in  $\chi_{\text{min}}^2$  by one.

Using equation (1) to fit the latest[8]  $pA$  data, one obtains

$$\sigma_0 = 2.28(1 \pm 0.07) \text{ nb}, \quad \alpha = 0.91 \pm 0.02, \quad \text{Cov}(\log \sigma_0, \alpha) = -0.0013 , \quad (5)$$

leading to a prediction  $B\sigma(Pb-Pb) = 0.88(1 \pm 0.13) \text{ nb}$ . The measured point[8],  $B\sigma(Pb-Pb) = 0.67 \pm 0.05 \text{ nb}$ , is, therefore, within  $2\sigma$  of the extrapolation. Adding further the dataset with light nuclei projectiles by assuming that no other source of suppression than the one operative in  $pA$  collisions exists in those cases too, one obtains,

$$\sigma_0 = 2.26(1 \pm 0.06) \text{ nb}, \quad \alpha = 0.914 \pm 0.013, \quad \text{Cov}(\log \sigma_0, \alpha) = -0.0007 , \quad (6)$$

leading to a prediction for the  $Pb-Pb$  cross section as  $0.904 \pm 0.078 \text{ nb}$ , which again is within  $2\sigma$  of the measured cross section. The smaller errors on the  $pA$  and  $A'A$  data[8], thus result in predictions with slightly better error estimates compared to the original results of Ref. [9]. However, the final measured  $Pb-Pb$  cross section has also moved up a little so that the measured cross section lies within  $2\sigma$  of the prediction irrespective of the inclusion or exclusion of the light nuclei  $A'A$  data in the fit.

---

<sup>3</sup>I thank Ruedi Burkhalter for pointing this out to me.

As mentioned earlier, the  $L$ -dependence of the  $J/\psi$  cross section yielded[8] a statistically lot more significant result than the  $5\sigma$  for the case discussed above. Using equation (2) in this case along with the  $\chi^2$  as defined in equation(3), we find

$$C = 45.2(1 \pm 0.13), \quad \sigma_{abs} = 6.64 \pm 1.11 \text{ mb} . \quad (7)$$

If we set, by hand, all errors on  $L$  to zero, then we get

$$C = 43.3(1 \pm 0.07), \quad \sigma_{abs} = 6.28 \pm 0.66 \text{ mb} , \quad (8)$$

which is in excellent agreement with the results in [8].

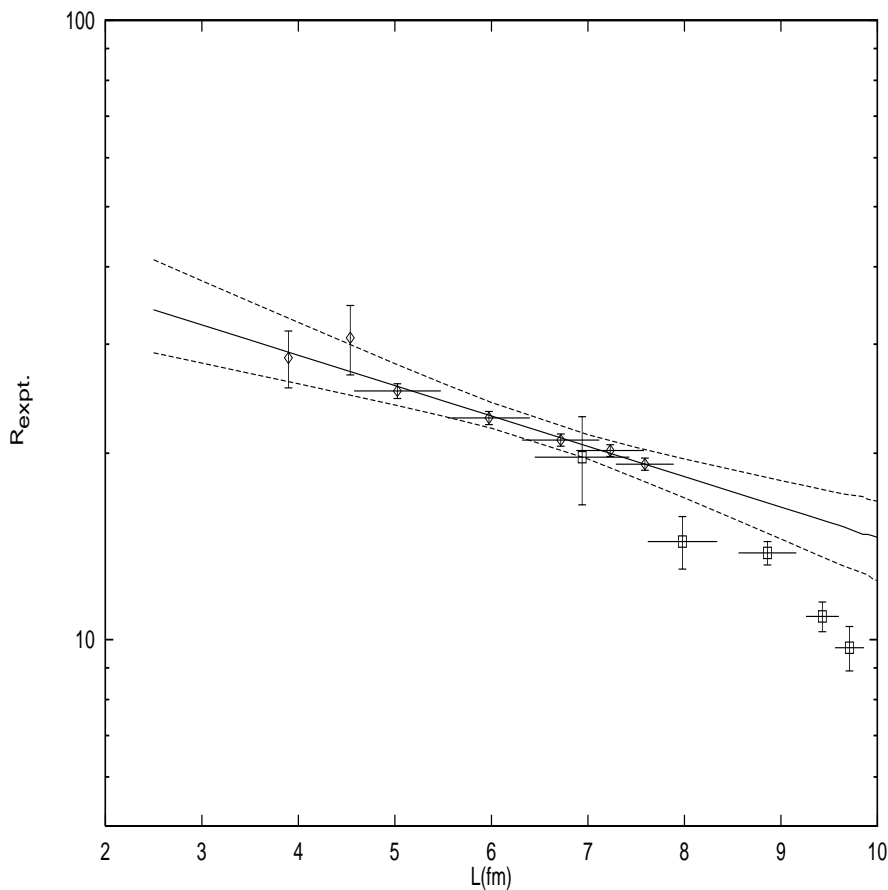


Figure 1: The ratio of  $J/\psi$  cross section and the Drell-Yan cross section vs.  $L$  in fm. The diamonds are NA38 data, shown along with the straight line fit, a  $2\sigma$  band around it, and the NA50 data (squares) with  $2\sigma$  errors on them.

Fig. 1 compares the fit (7) with the NA38  $pA$  and  $S-U$  data. A  $2\sigma$  band around the fit is shown along with the NA50  $Pb-Pb$  data with  $2\sigma$  error at each point. The band includes the effects of the full covariance matrix for the fit parameters in

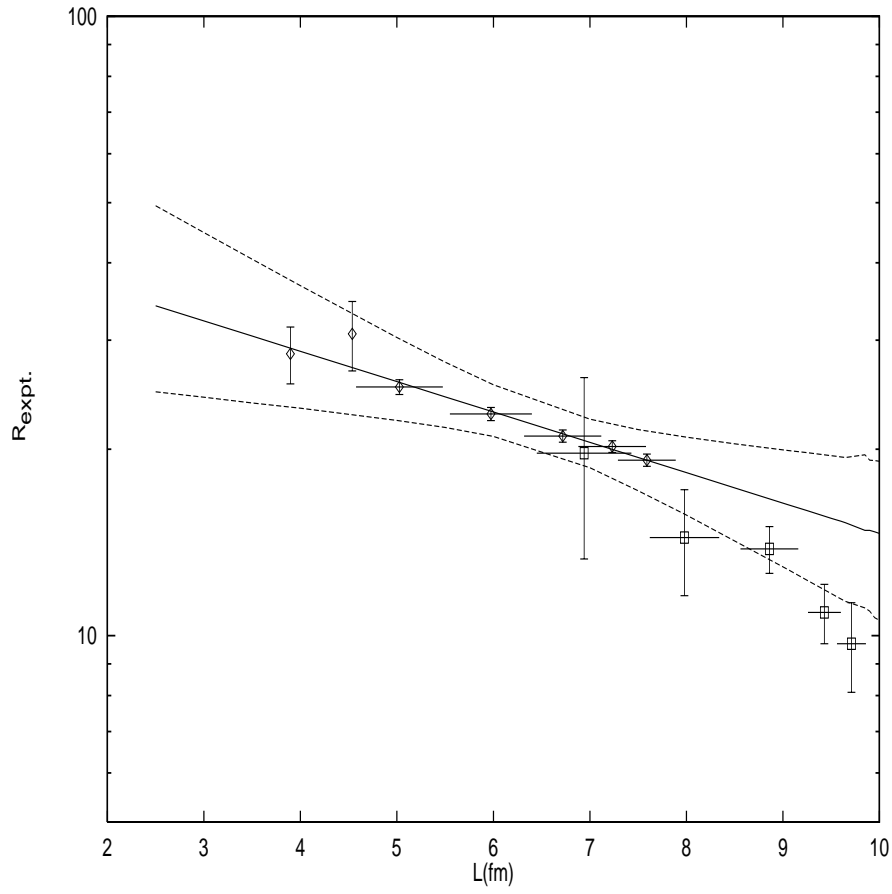


Figure 2: Same as Fig. 1 but with a  $4\sigma$  band around the fit and the NA50 data with  $4\sigma$  errors on them.

equation (7) using the trick mentioned above. Unlike the total cross section data, there is a now clear deviation of the  $Pb-Pb$  data from the theoretical prediction at a 95 % confidence level, especially for the two points at the largest  $L$ -values. They are compatible with the fit only at a  $4\sigma$  level, as shown in Fig. 2. Of course, in both figures one clearly sees that all the deviations are in the same direction, which adds further weightage to the observation of anomalous behavior. Nevertheless, our results suggest a much less stronger result, if one goes by the usual wisdom of requiring a  $5\sigma$  effect for a new discovery.

It may not be out of place to comment on 1) the origin of our different result vis-a-vis those in Ref. [8] and 2) the implications for the preliminary 1996 data. In both the cases, discussed above, Ref. [8] compares the ratio of the measured value to the theoretical prediction with unity whereas we compare the difference of the measured and theoretical cross sections. Both procedures will give same result provided the theoretical prediction has no errors at all, which is what seems to be assumed in Ref. [8]. Since the theoretical prediction has big errors, which stem in one case from large extrapolation and in another case from the fact that the fitted experimental data has errors in *both*  $x$  and  $y$  directions, we think our procedure is more appropriate. Of course, it is really the neglecting of the propagated errors on the predictions which gives rise to a larger result for the deviations, i.e., larger apparent anomalous suppression, than what the data warrant. The preliminary 1996 data [6] are mostly in agreement with the 1995 data and may be slightly higher up for the larger  $E_T$  or equivalently larger  $L$ . Since neither the  $pA$  nor the  $S-U$  data have changed, none of the fits reported here change; if the data were available using the same rescaling as in Ref. [8], one could directly put them on Figs. 1 and 2. An indirect comparison via the transverse energy plots of Ref. [6] yields a preliminary conclusion on the 1996 data that the anomalous suppression at any  $L$  will unlikely be more than  $4\sigma$  for them as well. The same will also hold true for any discontinuity in the data, if present.

In conclusion, we have shown that the spread in  $L$ , which arises due to the presence of many events in a given in  $E_T$  bin with varying  $L$ , causes it to be known less precisely than assumed previously. Taking into account this inevitable imprecision makes the theoretical prediction less accurate due to error propagation. However, the  $L$ -dependence of the  $J/\psi$  cross section shows a definite anomalous suppression at the 95 % confidence level, while the  $A'A$ -dependence of the cross section is not anomalous at that level. On the other hand, the anomalous suppression at each  $L$  is at best a  $4\sigma$  effect. Better data for lighter nuclei in finer bins of  $E_T$  are needed to improve the significance of the  $Pb-Pb$  results, as the dominant errors are in the theoretical predictions.

I wish to thank R. Burkhalter, H. Shanahan, K. Kanaya and A. Ukawa for discussions and persistent questions which led to this work. The kind hospitality of the all the members of the Center for Computational Physics, University of Tsukuba, Japan, where this work was done, is gratefully acknowledged.

## References

- [1] T. Matsui and H. Satz, *Phys. Lett.* 178 B (1986) 416.
- [2] R. V. Gavai and S. Gupta, *Phys. Lett.* B 216 (1989) 239; R. V. Gavai, S. Gupta and Sridhar K., *Phys. Lett.* B 227 (1989) 161.
- [3] D. Kharzeev and H. Satz, *Phys. Lett.* B 366 (1996) 316.
- [4] A. Capella, J. A. Casado, C. Pajares, A. V. Ramello and J. Tran Thanh Van, *Phys. Lett.* B 206 (1988) 354; C. Gerschel and J. Hüfner, *Phys. Lett.* B 207 (1988) 253.
- [5] J. Ftáčnik, P. Lichard and J. Pišut, *Phys. Lett.* B 207 (1988) 194; S. Gavin and M. Gyulassy and A. Jackson, *Phys. Lett.* B 207 (1988) 257; J. -P. Blaizot and J. -Y. Ollitrault, *Phys. Lett.* B 207 (1988) 263.
- [6] L. Ramello, Talk at the *Quark Matter* 1997, Tsukuba, Japan; A. Romana, Talk at the *Rencontre de Moriond* 1998, Les Arcs, France, March 1998.
- [7] M. Gonin *et al.* (NA50), Report at the *Quark Matter* 1996, Heidelberg, Germany, *Nucl. Phys.*, A 610 (1996) 404c.
- [8] The NA50 Collaboration, M. C. Abreu *et al.* *Phys. Lett.* B 410 (1997) 337.
- [9] R. V. Gavai and S. Gupta, *Phys. Lett.* B 408 (1997) 397.
- [10] See for example, W. H. Press, S. A. Teukolsky, W. T. Vetterling and B. P. Flannery, *Numerical Recipes in Fortran*, Cambridge University Press, 1994, p. 660.
- [11] See for example, J. R. Green and D. Margerison, *Statistical Treatment of Experimental Data*, Elsevier, Amsterdam, 1978.