Cold Nuclear Modification of *J/ψ* Production in *d+A* and *A+A* Collisions

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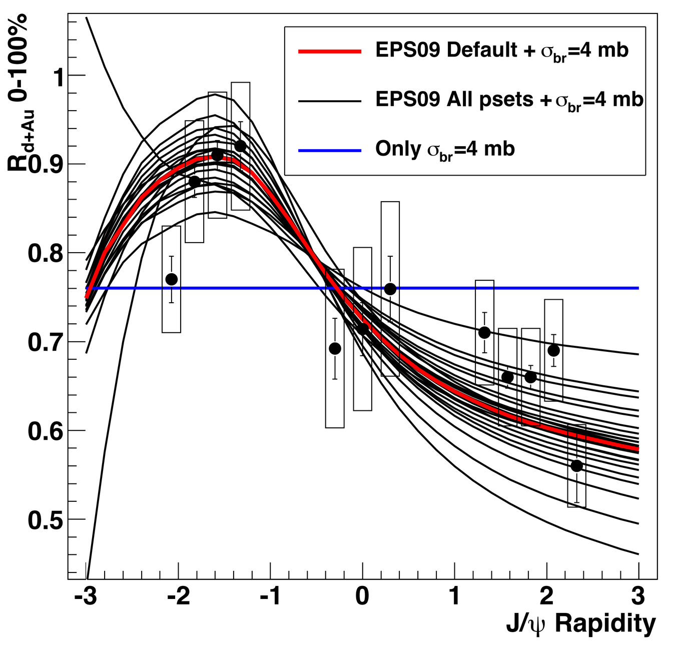


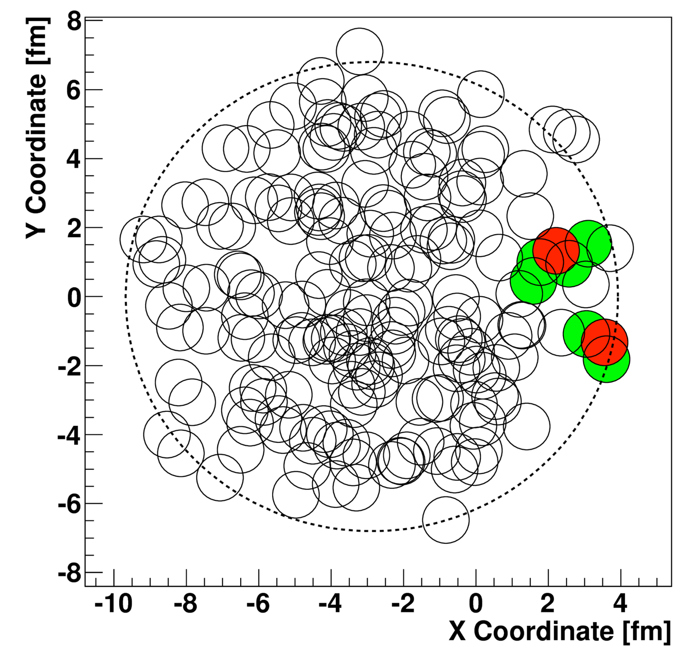
Strong cold nuclear matter (CNM) effects are evident in *J/ψ* yields in *p*(*d*)+*A* collisions, including shadowing of nuclear PDFs and break-up of the pre-*J/ψ* c-cbar pair in the nucleus. Shadowing may be parametrized by the EPS09 nuclear PDFs, while a break-up cross section may be used for nuclear break-up. Calculations of this nature give good qualitative agreement with R_{dAu} averaged across impact parameters, as can be seen on the left. However, the geometric (*b*) dependence of the modification is not well understood.

PHENIX *d*+Au data from arXiv:1010.1246
Calculations detailed in arXiv:1011.4534

The nuclear geometry is accounted for by starting with a Glauber MC of the initial nucleon-nucleon collisions. The nucleons are distributed according to a Woods-Saxon distribution for the gold nucleus and the Hulthen wave-function for the deuteron. 42 mb is used for the *N-N* inelastic cross section.

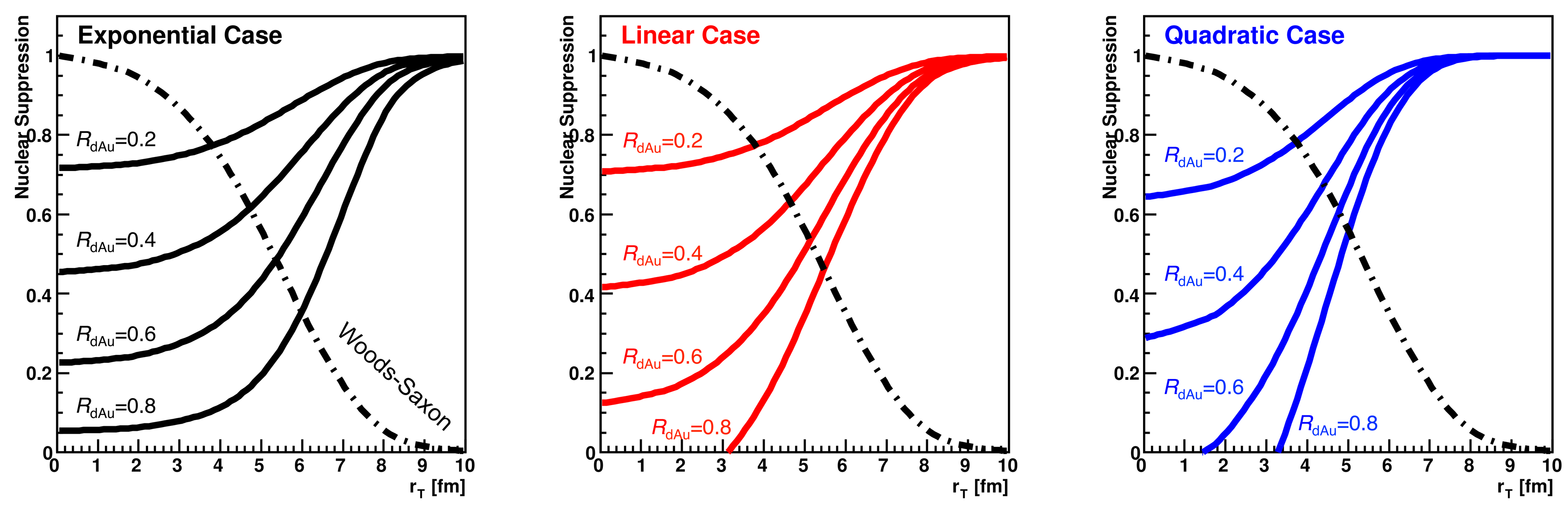
The distribution of collisions as a function of transverse radius (r_T) is kept track of, and can then be combined with the r_T distribution of PHENIX centrality classes for a direct comparison. In this way event-by-event fluctuations in the number of *N-N* collisions and path length are also taken into account.

In place of an average path length, the number of nucleons overlapping the path of the incoming nucleon are counted, allowing the event-by-event fluctuating path length to be used.



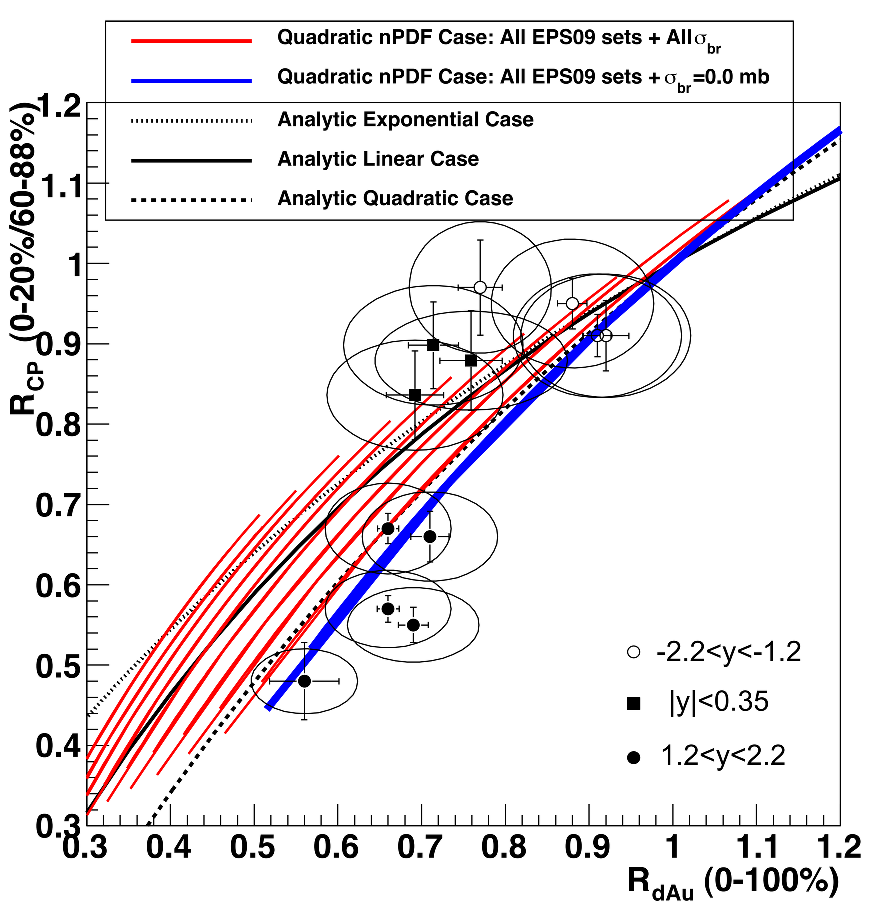
Assuming the modification depends on the density-weighted longitudinal thickness *L* of the nucleus, and given the average modification R_{dAu}(0-100%), the modification vs. r_T can be calculated for any functional form *f*(*L*).

To the right is the modification vs. r_T assuming *f*(*L*) is exponential, linear, or quadratic.



To test these different cases it is useful to compare to R_{CP}, which is effectively the ratio of small r_T to large r_T for the curves to the left.

The actual comparison is done by convoluting the curves with the PHENIX centrality distributions for an apples-to-apples comparison.



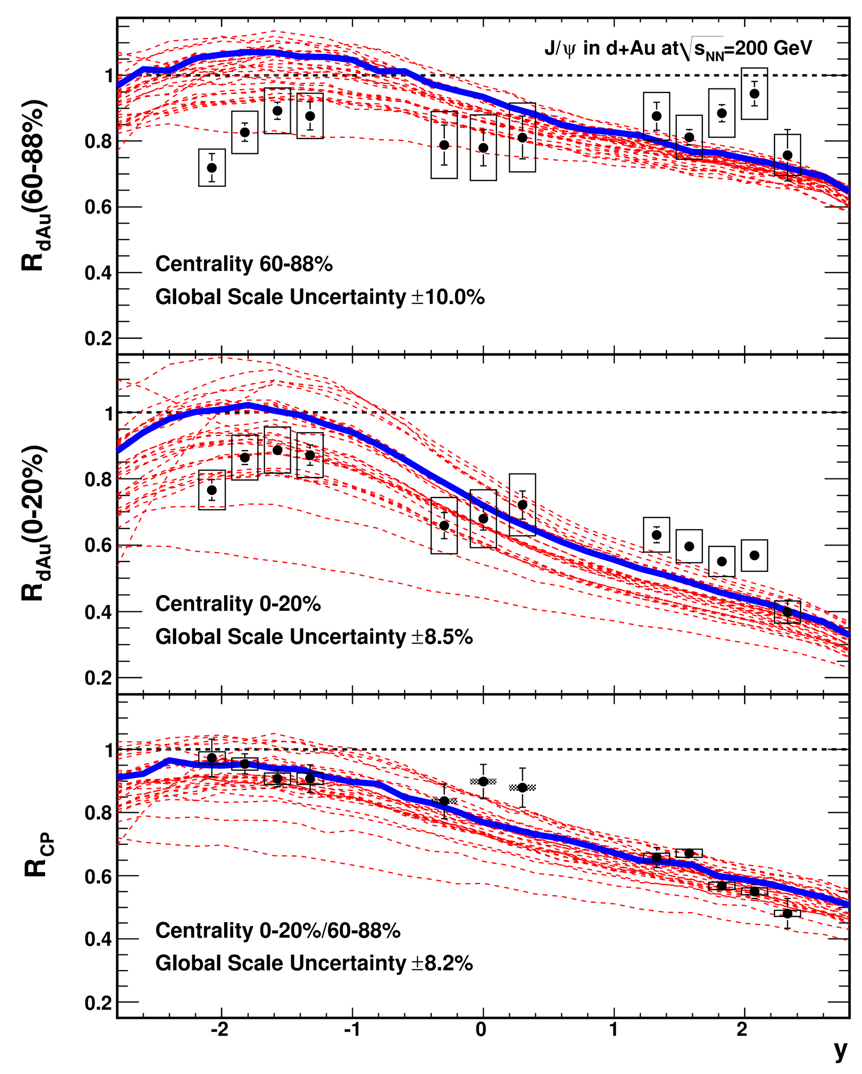
By plotting R_{CP} vs. R_{dAu}(0-100%), each of the above functional forms fall along a common curve (the "Analytic" cases in the figure). The blue curve represents the quadratic case, with inclusion of nuclear thickness fluctuations in the calculation above causing the deviation from the analytic quadratic case. Finally, the red lines are generated by adding in nuclear break-up with an exponential dependence in 2 mb increments.

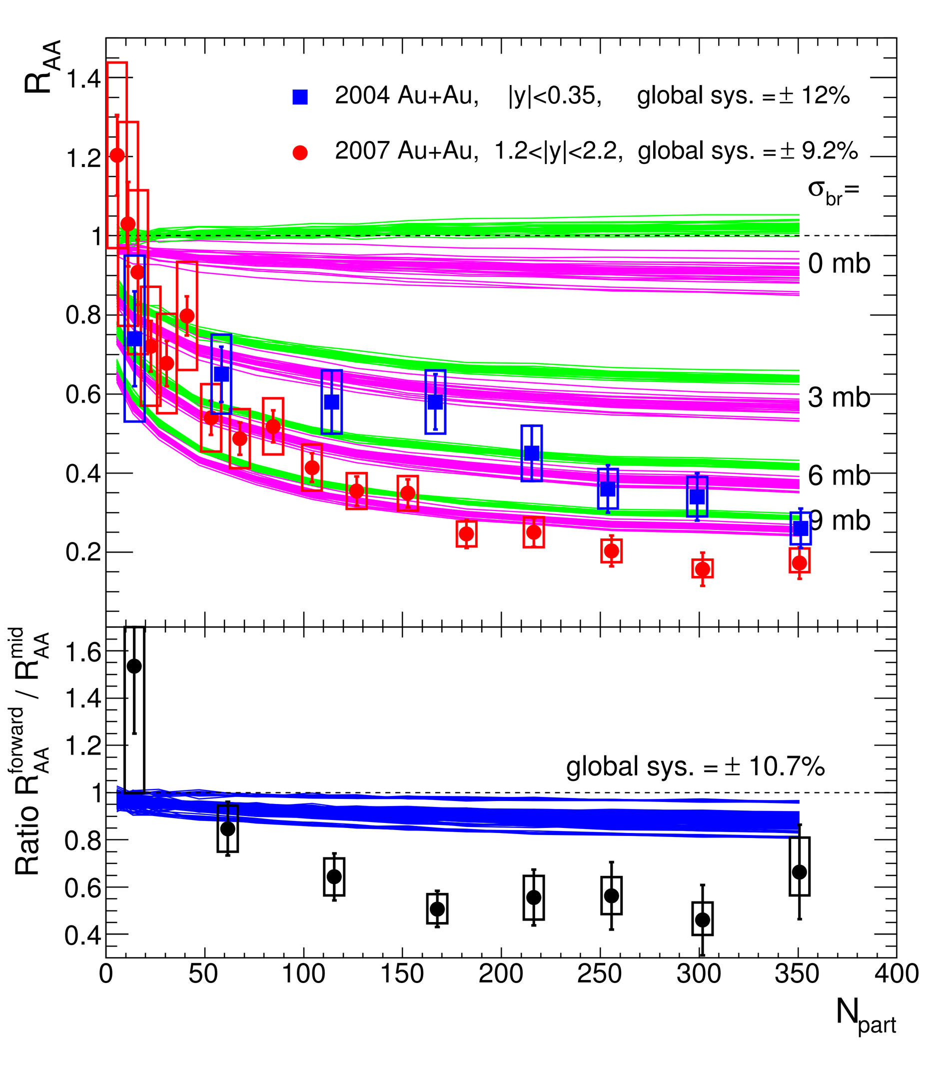
As described by PHENIX, the linear and exponential cases cannot describe the suppression. Here it can be seen that shadowing with a quadratic dependence (and thickness fluctuations) comes the closest.

Another effect that may be included is initial-state parton energy loss. Energy loss of the incoming gluon passing through the nucleus prior to the hard scattering results in a reduced probaility to produce a *J/ψ* as well as a shift to lower rapidity values for any produced *J/ψ*s.

Gluon energy loss is added to the previous CNM calculation by adding a factor based on the gluon's path length prior to the hard scattering, with either *L* or L^2 dependence fro the relative loss.

$\Delta E/E \sim L^2$ is used to calculate the curves in the figure to the right, and while it qualitatively agrees with R_{CP}, It doesn't do as well with R_{dAu} in the individual centrality bins.



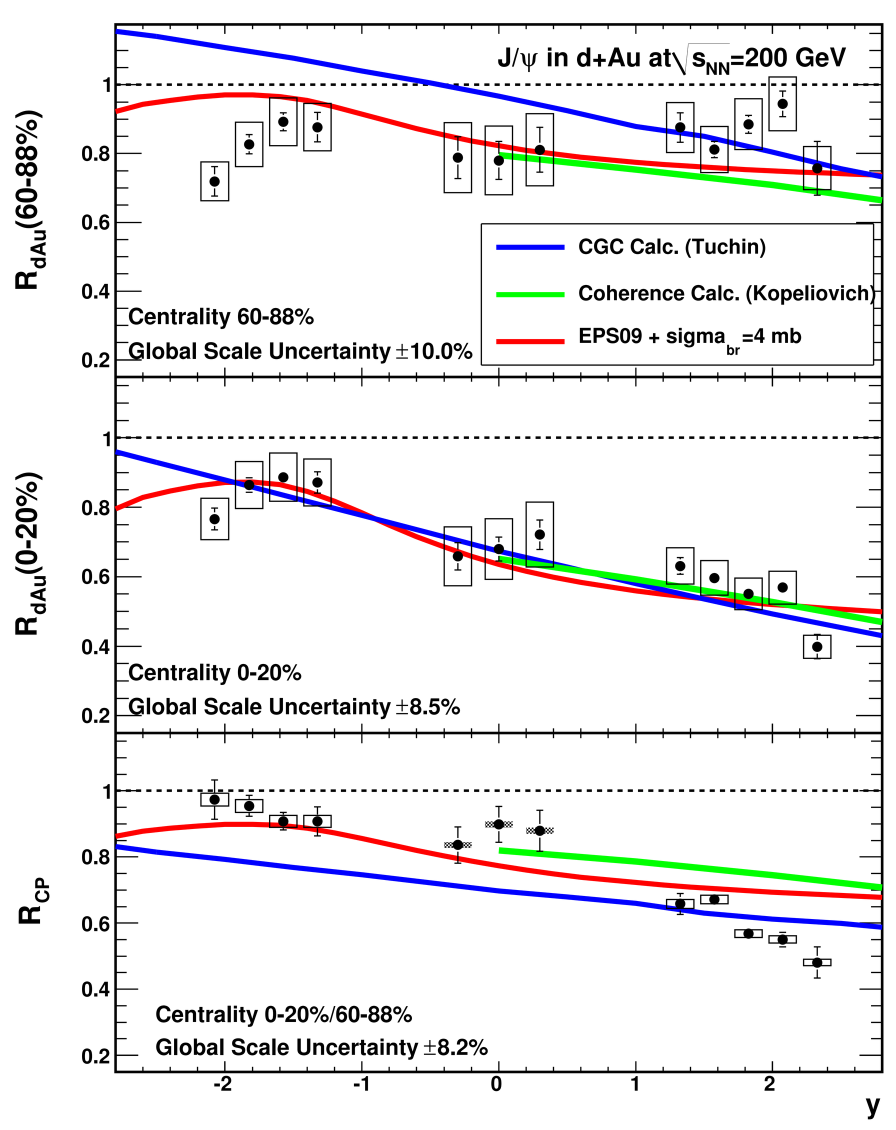


PHENIX Au+Au data from arXiv:1103.6269

The combination of the CNM described above (shadowing, nuclear break-up, and initial-state energy loss) may also be projected to Au+Au collisions using the same Glauber framework. To the right can be seen these calculations for both |y|<0.35 (green) and 1.2<|y|<2.2 (magenta), as well as the ratio of the forward to midrapidity.

The CNM effects cannot recreate the suppression seen in Au+Au without an improbably large break-up cross section (~9 mb). Additionally, none of the sets of curves can reproduce the large difference in suppression between rapidities.

Therefore, hot nuclear matter must contribute to the J/ψ suppression seen at PHENIX, and the larger suppression at forward rapidity remains unexplained.



Additional or other effects may be necessary to explain CNM *J/ψ* suppression. In the PHENIX paper, the data were compared with a color glass condensate calculation that incorporated suppression at low *x* from gluon saturation and enhancement from double-gluon exchange diagrams. More recent calculations following this framework [1] include a more accurate treatment of the nuclear geometry and the dipole-nucleus scattering amplitudes, and are consistent with recent calculations for the Au+Au case.

In an alternative calculation presented in [2], the *J/ψ* production is controlled by coherence and color transparency effects (green line).

[1] K. Tuchin, private communication
[2] B. Kopeliovich, I. Potashnikova, H. Pirner, and I. Schmidt (2010), arXiv:1008.4272.