# $J/\psi$ Suppression Measurements by the PHENIX Experiment at RHIC

Ermias T. ATOMSSA [*]

Laboratoire Leprince Ringuet, École Polytechnique/IN2P3
Palaiseau, 91128, France.

Suppression of the quarkonium $J/\psi$ ($c\bar{c}$) in heavy ion collisions has long been used as a signature of deconfinement [2]. Recent measurements by the PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC) show a similar anomalous suppression as the one observed by the NA50 and NA60 experiments at CERN. Data from PHENIX in various colliding system are presented. Striking features that challenge traditional views are pointed out.

## 1 $J/\psi$ suppression

Heavy ion collisions provide a unique experimental way to create and characterize the Quark Gluon Plasma (QGP), a hot and dense matter that lattice QCD predicts to be produced at high temperature energy density and. Products of hard processes, which take place in the early stage of the collision, are highly sensitive probes of the evolution of the created system. Suppression of the $J/\psi$ quarkonium, which constitutes such a probe, has been measured by the PHENIX experiment at RHIC in various interactions, as a function of impact parameter, rapidity and transverse momentum.

One convenient way to define modification in AB type heavy ion collisions (where A and B represent atomic masses of colliding nuclei) is as the ratio of the $J/\psi$ yield in heavy ion collisions to the one expected from pQCD, as measured by the yield in p+p interactions scaled by the average number of binary nuclear collisions ($N_{coll}$) that take place in AB type collisions ($R_{AB}$).

$$R_{AB}(y,p_T) = \frac{dN_{AB}(y,p_T)/dydp_T}{< N_{coll} > dN_{pp}(y,p_T)/dydp_T}$$

Different physical effects can contribute to the experimentally observed suppression ratio. At RHIC energies, direct $J/\psi$'s are produced mostly through gluon-gluon fusion in nucleon-nucleon scatterings early in the collision. At this level, a modification (called shadowing) of gluon PDFs in nuclei can influence the suppression measured at the end. In addition, the initial production cross section is enhanced by a feed down component from excited charmonium states that is poorly constrained by experimental measurements.

Other physical phenomena can modify the suppression ratio after $J/\psi$ formation. One such process is the absorption by nucleons in receding collision fragments. This contribution is called nuclear absorption, and may be sensitive to the formation mechanism of $J/\psi$. Shadowing and nuclear absorption are known as Cold Nuclear Matter (CNM) effects. Finally there are effects that might enhance the ratio by the creation of $J/\psi$ through the recombination of uncorrelated $c$ and $\bar{c}$ pairs from a deconfined medium. It is thus a complicated task to disentangle all these effects and isolate the contribution from dissociation by a possible QGP.

---

[*] For the PHENIX Collaboration.

## 2 $J/\psi$ measurements in PHENIX

The PHENIX detector at the Relativistic Heavy Ion Collider (RHIC) can identify and measure electrons with a pair of mid rapidity spectrometers that cover $2 \times 90^\circ$ in azimuth and $|y| < 0.35$ in rapidity, as well as muons with a pair of forward rapidity spectrometers that cover $360^\circ$ in azimuth and $1.2 < |y| < 2.2$ in rapidity. This has allowed to do $J/\psi$ suppression ratio measurements for different colliding systems (p+p, d+Au, Au+Au and Cu+Cu) as a function of rapidity, collision centrality and transverse momentum [3, 4, 5, 6].

Event centrality characterization is done by using information from global detectors: measurements of charged multiplicity by a Beam Beam Counter and/or energy deposit by a Zero Degree Calorimeter are used to divide the total cross section into centrality classes. A Glauber model calculation in conjunction with response simulation of global detectors is used to calculate the average $N_{coll}$ for the events in each centrality class [7].

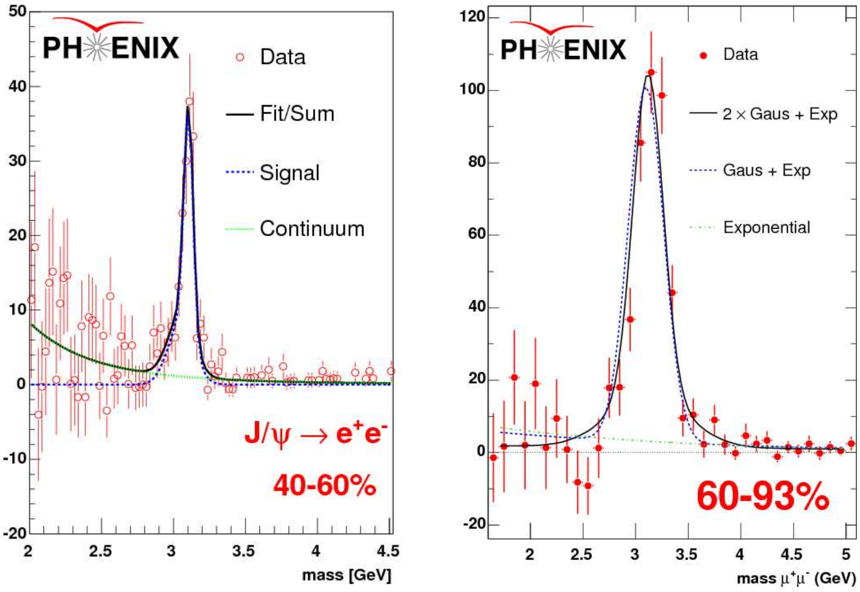

Figure 1: Left: Invariant mass spectrum of electron-positron pairs. Right: Invariant mass spectrum of muon pairs. Both plots are after subtraction of the combinatorial background.

Differential yields of $J/\psi$ are measured through invariant mass spectra of lepton pairs (cf. Figure 1). The combinatorial background from uncorrelated unlike sign lepton pairs is estimated by mixing like sign leptons from different events. After combinatorial background subtraction, the spectra are fitted by various combinations of Gaussian and exponential functions to account respectively for $J/\psi$ mass peak and residual backgrounds including open charm/beauty decays and Drell-Yann processes. The average value of the Gaussian integrals from the different fits is used as $J/\psi$ yield and the dispersion is included in the systematical errors.

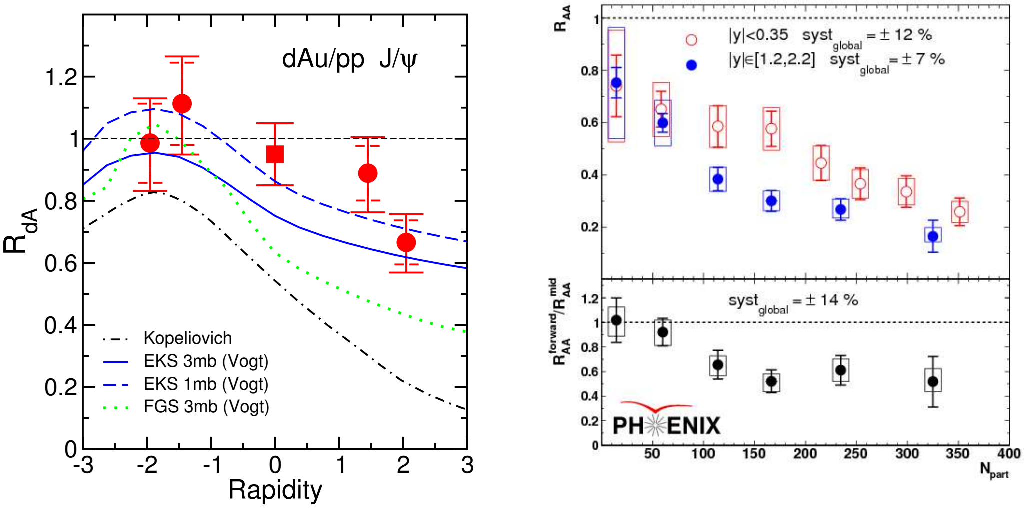

Figure 2: Left: $R_{dA}$ as a function of rapidity for $J/\psi$'s measured by PHENIX in d+Au collisions [4]. Right: $R_{AA}$ for Au+Au collisions as a function of centrality for two rapidity ranges in upper panel, and the ratio between two in lower panel [5].

## 3 Suppression ratios from different colliding systems

On the left side, Figure 2 shows $R_{dA}$ measurements by PHENIX from $\sim 1.5\mu b^{-1}$ worth of d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. This control experiment is intended to examine the contribution of CNM effects, because no QGP formation is expected in dA type collisions. Three models incorporating shadowing and nuclear absorption (with different cross sections) are plotted for comparison. The EKS shadowing parametrization [8] seems to reproduce the data better. Given the experimental uncertainties it is impossible to discriminate between the two absorption cross sections ($1mb$ and $3mb$).

On the right side, Figure 2 shows the $J/\psi$ suppression ratio in Au+Au collision at $\sqrt{s_{NN}} = 200$ GeV interactions measured by PHENIX as a function of collision centrality (more central for higher $N_{coll}$). The Au+Au measurements are from the 2004 data set representing $\sim 160\mu b^{-1}$. Normalization is done using $\sim 3.6pb^{-1}$ of p+p collision data taken in 2005 [3]. The results are given as a function of the number of nucleons participating in inelastic collisions ($N_{part}$).

As expected, the modification factor approaches unity for peripheral collisions (small $N_{part}$). On the other hand, for very central collisions, (large $N_{part}$), a suppression factor of the order of five is observed at forward rapidity. Indirect comparisons [9, 10] show that this suppression ratio goes beyond what can be explained by extrapolations from d+Au measurements. Nevertheless two striking features are seen in these results:

1. The suppression ratio at mid rapidity is in very good agreement with the one measured by the NA50 and NA60 experiments at lower energy ($\sqrt{s_{NN}}$ ~17 GeV) with various ions (S+U, In+In, Pb+Pb) whereas the energy density reached is expected to be much smaller than at RHIC.

2. The suppression seen at forward rapidity is higher than the one observed at mid rapidity (cf. bottom panel of Figure 2).

These two observations, have led to the idea that the suppression seen in heavy ion collisions is not dominated by suppression mechanisms that increase with local energy density.

On the other hand models that assume suppression that grows with local density describe well the SPS data, but overestimate suppression at RHIC. They also fail to reproduce the mid to forward rapidity ratios of suppression factors.

Although regeneration models provide an alternative, it is difficult to confirm them based only on the $R_{AA}$ patterns due to poor constraints on their input parameters (for instance, the $c\bar{c}$ cross sections in similar conditions) to these models. To illustrate this point Figure 3 shows a few of the models [11, 12, 13, 14] that combine regeneration scenarios with suppression. Looking at distributions of other variables usually helps because recombined $J/\psi$ tend to populate different phase space regions than $J/\psi$ from direct pQCD processes. For instance the $< p_T^2 >$ variation as a function of centrality has already been used to this objective to some extent [15], but is again complicated by other mechanisms that contribute to the looked for effect. Another discriminating variable, is the elliptic flow ($v_2$) of $J/\psi$ The current run 7 with somewhat larger statistics than previous runs and new global detectors will hopefully enable PHENIX to do these measurements.

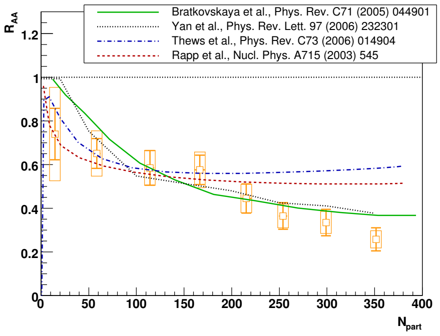

Figure 3: Predictions of various regeneration models compared to the mid rapidity result.

## References

[1] Slides:
`http://indico.cern.ch/contributionDisplay.py?contribId=197&sessionId=5&confId=9499`

[2] T. Matsui et al. *Phys. Lett.*, B178:416, 1986.

[3] A. Adare et al. *Phys. Rev. Lett.*, 98:232002, 2007.

[4] S. S. Adler et al. *Phys. Rev. Lett.*, 96:012304, 2006.

[5] A. Adare et al. *Phys. Rev. Lett.*, 98:232301, 2007.

[6] H. Pereira Da Costa. *Nucl. Phys.*, A774:747–750, 2006.

[7] K. Adcox et al. *Phys. Rev. Lett.*, 86:3500–3505, 2001.

[8] K. J. Eskola et al. *Eur. Phys. J.*, C9:61–68, 1999.

[9] Raphael Granier de Cassagnac. hep-ph/0701222.

[10] R. Vogt. *Acta Phys. Hung.*, A25:97–103, 2006.

[11] R. L. Thews et al. *Phys. Rev.*, C73:014904, 2006.

[12] Li Yan et al. *Phys. Rev. Lett.*, 97:232301, 2006.

[13] E. L. Bratkovskaya et al. *Phys. Rev.*, C71:044901, 2005.

[14] L. Grandchamp et al. *Nucl. Phys.*, A715:545–548, 2003.

[15] R. L. Thews. *Nucl. Phys.*, A783:301–308, 2007.