PROCEEDINGS OF SCIENCE

Quarkonia measurements from PHENIX

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The measurement of quarkonia production in relativistic heavy ion collisions provides a powerful tool for studying the properties of hot and dense matter created in these collisions. To have a complete understanding, however, such measurements must cover a wide range of quarkonia states, collision energies and colliding species. The PHENIX detector recently collected high statistics data using combinations of heavy ion species and beam energies in a broad rapidity range. We present here the most recent measurements of J/ψ, ψ' production in d+Au, Au+Au and Cu+Au collisions at $\sqrt{s_{NN}}$ =200 GeV, 62.4 GeV and 39 GeV in mid ($|y|$ <0.35) and forward rapidities ($1.2 < |y| < 2.2$).

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1. Introduction

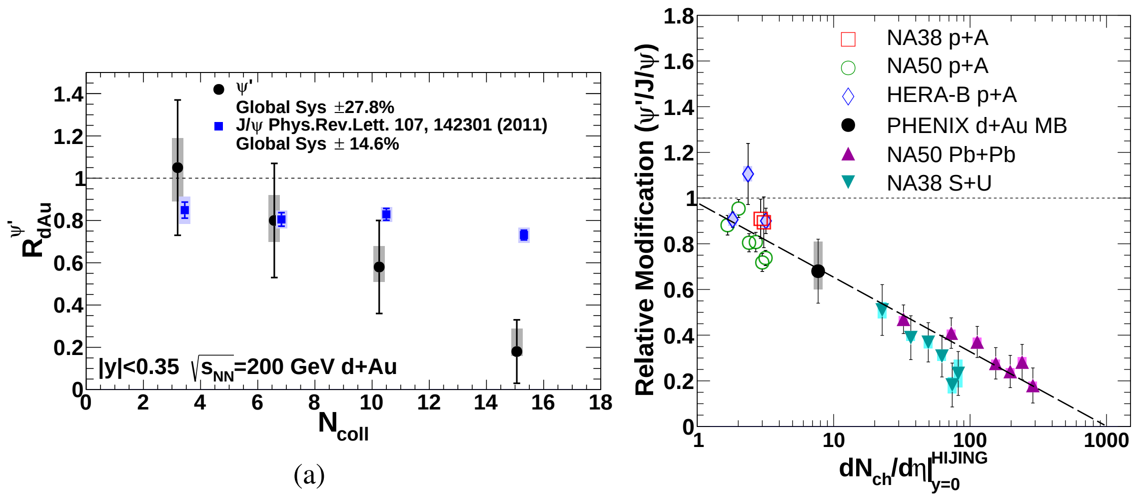
The Relativistic Heavy Ion Collider (RHIC) was build to collide heavy nuclei at high energies in order to achieve a high temperature and energy density where confined normal hadronic matter is no longer exists but a new state of matter created where partons are deconfined – called the Quark Gluon Plasma (QGP). Quarkonia ($q\bar{q}$) states are useful tools to study the properties of QGP since they are expected to be suppressed due to effects like color screening in the medium which will hinder their production [1]. Therefore, the observed hadron yield is expected to be lower than that expected from binary collision scaling. This suppression is quantified in terms of the nuclear modification factor R_{AA}:

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN^{AA}/dy}{d\sigma^{pp}/dy} \tag{1.1}$$

where dN^{AA}/dy is the invariant yield in Au+Au collisions, $d\sigma^{pp}/dy$ is the p+p cross-section and $\langle T_{AA} \rangle$ is the nuclear overlap function. The same measurements are also preformed in d+Au collisions where the formation of the hot, dense partonic medium is not expected and initial-state effects prevails – the modification factor is referred as R_{dAu}.

2. ψ' Measurement in 200 GeV d+Au collisions

Modifications of quarkonia yields within a nuclear target are often termed as "cold-nuclear-matter" (CNM) effects which gives insight about the evolution of $q\bar{q}$ in a nuclear environment are studied in d(p)+Au collisions. We present the results of two quarkonia states (J/ψ and ψ') in d+Au collisions at $|y| < 0.35$ and $\sqrt{s_{NN}}$ =200 GeV [2]. Measuring and understanding CNM effects are critical to interpreting the results for J/ψ production in nucleus-nucleus collisions.



(a) (b)

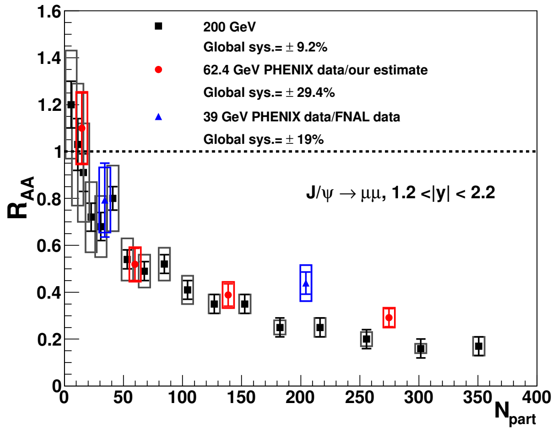
Figure 1: (a) ψ' nuclear modification factor, R_{dAu} as a function of N_{coll} (b) The relative modification of ψ' to the J/ψ as a function of the charged multiplicity.

Figure 1(a) shows the nuclear modification factor R_{dAu} of J/ψ and ψ' as a function of N_{coll}. In peripheral collisions we observe a similar suppression for ψ' and J/ψ, while in central collisions the most weakly bound ψ' is more strongly suppressed – a factor of $\sim$3 larger than the observed supperssion for inclusive J/ψ production. Note that the J/ψ R_{dAu} plotted here is not corrected for the feed-down from ψ' and χ_C.

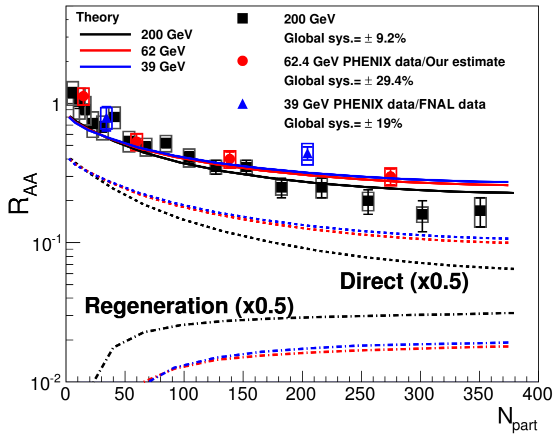
Figure 1(b) presents a comparison of the relative modification of the ψ' as a function of charged particle multiplicity for different collision energy and species. HIJING event generator was used to calculate dN_{ch}/dy at $y = 0$ for all the experimental points. As seen in the figure the relative modification scales very well with the charged multiplicity at mid rapidity.

3. J/ψ Measurement at 39 and 62.4 GeV Au+Au collisions

PHENIX measured a strong J/ψ suppression (a factor of ≈ 5 for the most central collisions) at both mid and forward rapidities in Au+Au collisions at 200 GeV [3]. This suppression is very similar to that measured at the CERN-SPS at $\sqrt{s_{NN}} = 17.2$ GeV Pb+Pb collisions. This contradicts the color screening interpretation that the dissociation of the quarkonia states will increase with energy density. It is clear that additional effects like those from "cold nuclear matter" effects and additional QGP mechanisms (e.g. coalescence, energy loss) are in play. PHENIX extended the J/ψ measurements to the lower energies $\sqrt{s_{NN}} = 39$ and 62.4 GeV in order to disentangle different competing physics processes which might contribute [4].



(a)



(b)

Figure 2: (a) J/ψ R_{AA} results at 39, 62.4 and 200 GeV (b) a model comparison which describes the data very well.

Figure 2(a) shows the J/ψ suppression at forward rapidities ($1.2 < |\eta| < 2.2$) at three energies, $\sqrt{s_{NN}} = 39$, 62.4 and 200 GeV as a function N_{part}. At lower energies J/ψ suppression is similar to that at 200 GeV at forward rapidity. Although there is a modest decrease of suppression in central collisions at 39 GeV, overall they agree within systematic errors. The similarity between different energies is the cumulative effect of the different competing physics processes. However the strength of these processses remain unclear without detailed understanding of the J/ψ in a nuclear target or CNM effects. These effects are expected to be different in at each collision energy. It is therefore important to measure these effects experimentally in d(p)+Au collisions at the same energies as Au+Au collisions.

A theory calculation which includes CNM effects, regeneration and QGP suppression for J/ψ production at the forward rapidity is compared to the data in figure 2(b). Both the contributions of direct J/ψ and regenerated J/ψ are shown separately. It appears that QGP suppression decreases while going from 200 GeV to 39 GeV as seen in the direct component but the regeneration effects gets stronger at higher energies. The regeneration component is expected to increase with collision energy due to increase in the total number of charm pairs produced. The inclusion of the regeneration component resulted in a similar suppression at all energies and PHENIX measurements are consistent with the theoretical calculations within global systematic uncertainties.

4. J/ψ Measurements at 200 GeV Cu+Au collisions.

RHIC also collided asymmetric heavy ions Cu+Au, allowing the exploration of the unique phase space created in such collisions. In general, the larger Au nucleus contributes more participants than the Cu nucleus – resulting an asymmetry between backward and forward rapidities. For central collisions, the smaller radius Cu is entirely swallowed by interacting with the larger gold nucleus.

The current interpretation of the heavy ion J/ψ suppression results require both cold- and hot-nuclear matter effects, although the true relative contribution is difficult to disentangle. For this asymmetric system it is expected that QGP effects are dominant but colliding different systems, at the same energy can provide an insight to the relative importance of such effects.

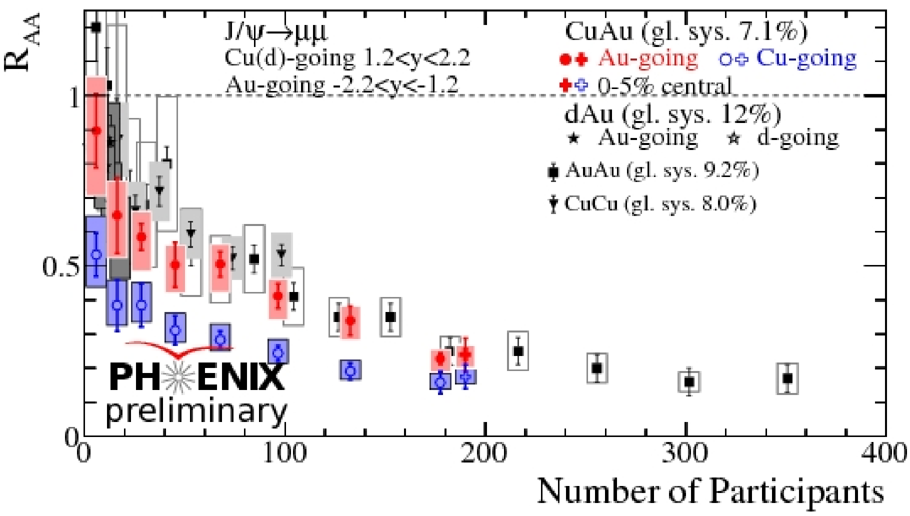


Figure 3: J/ψ suppression in Cu+Au collision and a comparison with other systems like Au+Au, d+Au and Cu+Cu.

Figure 3 shows the measured R_{AA} in Cu+Au collisions and compared with other systems like d+Au, Cu+Cu and Au+Au measurements [5]. The suppression in the Au going direction is similar to that in Au+Au collisions but a stronger suppression is seen in the Cu going direction. Cu+Au points are presented in 10% centrality slices except for the most central point shows a 0-5% central bin which represents the events where Cu nucleus is wholly swallowed by Au nucleus. The CNM effects are important to understand this difference, since Cu-going direction is sensitive to the low-x gluon in the Au nucleus – yielding a stronger suppression for the Cu doing direction.

5. Summary

RHIC-PHENIX program provides a large degree of freedom to study quarkonia in heavy ion collisions. PHENIX has measured different quarkonia states using combinations of heavy ion species and beam energies in a broad rapidity range. We find that ψ' production is heavily suppressed in central d+Au collisions at 200 GeV. An approximate scaling of the relative modification of ψ' to the J/ψ with charged particle multiplicity at mid rapidity is noticed. The J/ψ R_{AA} at 39 and 62.4 GeV is similar to that measured in 200 GeV which is consistent with the theoretical calculation which shows a balance in effects of more QGP suppression as well as more regeneration at higher energy collisions. Asymmetric collisions like Cu+Au show a stronger suppression in the Cu going direction than Au going direction.

References

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