

Beam energy scan results from PHENIX

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Abstract. Probes like J/ψ and π^0 production are very important for studying the properties of the strongly interacting partonic medium created in heavy ion collisions. Their production is strongly suppressed in $\sqrt{s}=200$ GeV $Au + Au$ collisions, in comparison to the expectation from binary collision scaled $p + p$ collisions. The recent low-energy scan at RHIC provided the PHENIX collaboration with an opportunity to study the evolution of the suppression at $\sqrt{s}=39$ and 62.4 GeV center of mass energies in order to disentangle multiple contributing mechanisms. The suppression of J/ψ observed is similar to those previously measured at 200 GeV. In contrast neutral pion suppression shows a distinct energy dependence at moderate p_T region of the central collisions.

1. Introduction

The theory of Quantum Chromodynamics (QCD) predicts a phase transition from hadronic matter to a deconfined Quark Gluon Plasma (QGP) at high temperature and energy density. The Relativistic Heavy Ion Collider (RHIC) was built to achieve these conditions by colliding heavy nuclei at very high energies in order to test the prediction of QCD and understand the properties of the medium. One of the powerful probes is a hard parton scattered in the early stage of the collisions. The scattered parton then passes through the created matter and fragments. If a dense, colored medium is formed in $Au + Au$ collisions, these hard-scattered partons may lose energy while traversing some of it. In case of quarkonia ($q\bar{q}$) bound states like $J/\psi(1S)$, the suppression mechanism is thought to be very different as there will be other additional effects like color screening in the medium which may hinder its production. Therefore, the observed hadron yield will be lower than that expected from binary collision scaling. This suppression is quantified in terms of the nuclear modification factor R_{AA} :

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN^{AA}/dy}{d\sigma^{pp}/dy} \quad (1)$$

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 PHENIX experiment previously measured R_{AA} for J/ψ and π^0 production at 200 GeV $Au + Au$ collision and found a strong suppression in the most central collisions [1]. The measured J/ψ suppression was similar to that measured at CERN-SPS energies in $Pb + Pb$ collisions at



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$\sqrt{s_{NN}} = 17.2$ GeV. This is in contradiction with the color screening interpretation that the suppression is expected to increase at higher temperature. So additional effects are need to be investigated. On the other hand the π^0 production is suppressed in $Au + Au$ collisions while it is observed to be enhanced in the lighter system $Cu + Cu$ at $\sqrt{s_{NN}} = 22.4$ GeV. In order to study the transition of enhancement to suppression of $\pi^0 R_{AA}$ and shine light on the J/ψ puzzle, RHIC started the beam energy scan program in 2010 by varying the beam energy and studying the effect on R_{AA} . This is an unique characteristic of RHIC to be able to collide different combination of species in a wide range of energies. Measurement of R_{AA} in a wide range of system energies is an important diagnostic means that will help quantifying the medium properties. We present new measurements of π^0 and $J/\psi R_{AA}$ at lower energies at $\sqrt{s_{NN}} = 39$ and 62.4 GeV $Au + Au$ collisions.

2. π^0 Measurement at 39 and 62.4 GeV

Neutral pion productions were measured at midrapidity ($|y| < 0.35$) in several energies of $Au + Au$ collisions. Our earlier π^0 measurements in $\sqrt{s_{NN}} = 130$ and 200 GeV of $Au + Au$ collisions revealed a strong suppression at high p_T , which was interpreted very well by the partonic energy loss model in the medium [1]. Additionally data from $\sqrt{s_{NN}} = 200$ GeV $d + Au$ collisions showed no suppression or enhancement indicating that the hadron suppression is a final state effect.

Moreover, the PHENIX experiment also studied π^0 production in a lighter collision system, $Cu + Cu$, at three energies ($\sqrt{s_{NN}} = 22.4, 62.4$ and 200 GeV). An enhancement was observed at 22.4 GeV but their production was suppressed at higher energies. This was interpreted as the interplay of the multiple soft scattering (Cronin effects) in the medium at various energies. During the beam scan program in 2010, PHENIX collected data at $\sqrt{s} = 39$ and 62.4 GeV $Au + Au$ collisions. These energies were specifically chosen to study this transition from enhancement to suppression as a function of collision energy in order to constrain the energy loss models.

Neutral pions are reconstructed via their $\pi^0 \rightarrow \gamma\gamma$ decay with the electromagnetic calorimeter (EMCal). Yields were extracted on statistical means by subtracting the photon pairs from the combinatorial background estimated by event-mixing in each p_T and centrality bin [2]. In order to compute R_{AA} , baseline $p + p$ measurements are needed. Corresponding $p + p$ reference data at 62.4 GeV were collected earlier in 2006 by PHENIX but RHIC was never run at 39 GeV $p + p$ collisions. Therefore, $p + p$ data from Fermilab E706 were used as a baseline for 39 GeV. Figure 1 shows the nuclear modification factor in most central 0 – 10% and mid-peripheral 40 – 60% of $Au + Au$ collisions at $\sqrt{s_{NN}} = 39, 62.4$ and 200 GeV. There is a significant suppression in the most central collisions at all three energies. In the mid-peripheral bin (40-60%), 39 GeV points are consistent with unity above $p_T > 3$ GeV/c but there is a suppression in all p_T region at both 62.4 and 200 GeV. The R_{AA} match well at all three energies at low or high p_T but it gets weaker in the intermediate- p_T region for the lower energies. pQCD calculations are also shown (solid lines) for the most central (0 – 10%) collisions which were used to successfully describe the 200 GeV $Au + Au$ data but failed to describe the new measurements at 39 and 62.4 GeV. Only a qualitative agreement of turnover point of the R_{AA} curves moves to higher p_T at lower collision energies is noticeable. The bands are the newly calculated results with a similar framework but with reduced Cronin-effect which are in better agreement with data [2].

Figure. 2 is the p_T averaged R_{AA} in the region above $p_T > 6$ GeV as a function of the number of participants. A similar suppression is observed at 62.4 and 200 GeV but it gets

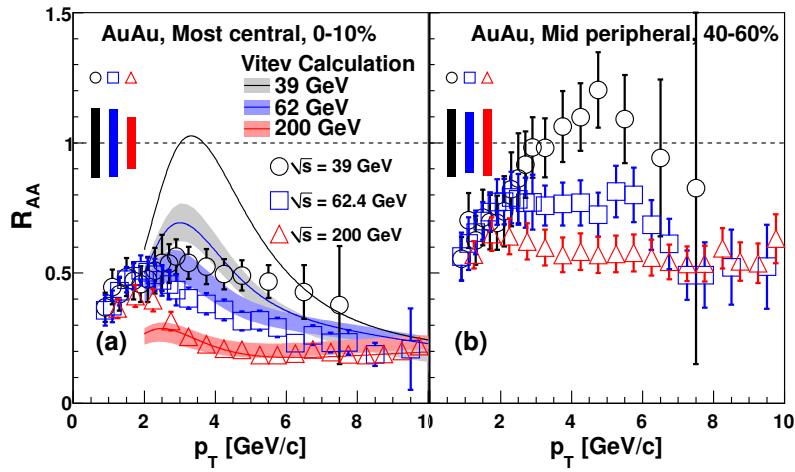


Figure 1. π^0 Nuclear modification factor in $Au + Au$ collisions for the most central 0-10% and mid-peripheral 40-60% bin. Also shown for central collisions are two pQCD calculations with Cronin-effect (solid lines) and with the Cronin-effect reduced (bands) for all three energies.

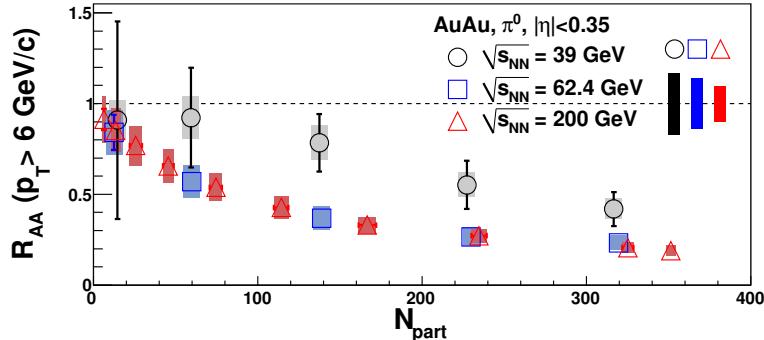


Figure 2. π^0 Nuclear modification factor for $p_T > 6$ GeV.

weaker the lower energy. The new measurements of π^0 suppression over wide energy range will help constrain the energy-loss models.

3. J/ψ Measurement at 39 and 62.4 GeV

Quarkonia bound states are expected to be suppressed in the Quark Gluon Plasma (QGP) due to color screening [3]. 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. This suppression is very similar to that measured at the CERN-SPS at $\sqrt{s_{NN}} = 17.2$ GeV $Pb + Pb$ collisions [4]. This contradicts the color screening interpretation that the dissociation of the quarkonia states will increase with energy density. It was clear that there are additional classes of effects like “cold nuclear matter” effects that are not due to the QGP 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 [5] in order to disentangle different competing

physics processes which might contribute. A broad measurement over $\sqrt{s_{NN}}$ will not only vary the temperature and density of the medium but also the $c\bar{c}$ production and cold nuclear effects (CNM).

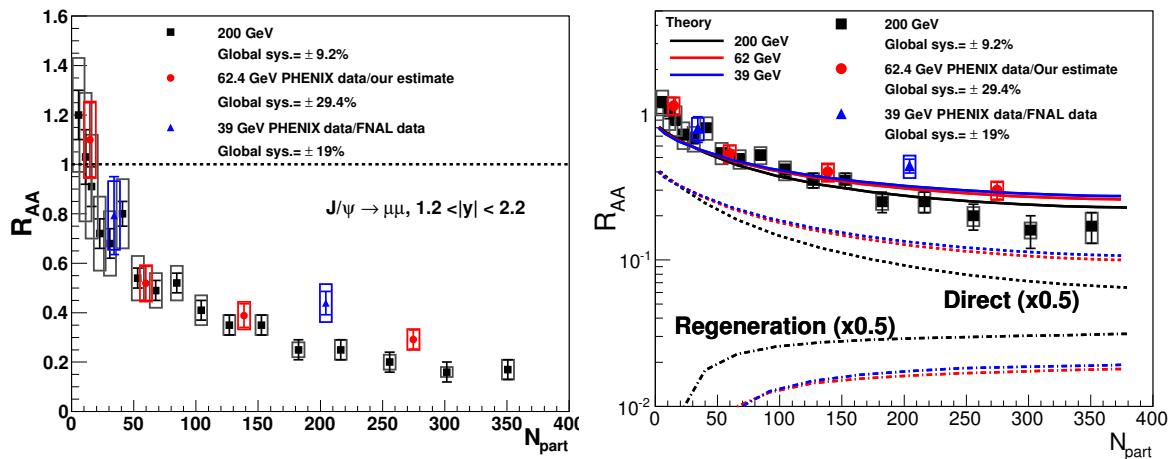


Figure 3. J/ψ R_{AA} and model comparison.

Two forward spectrometers composed of the Muon Tracker and Muon Identifiers are used to reconstruct the muon tracks. The J/ψ candidates were reconstructed via the dimuon channel in the rapidity range $1.2 < |\eta| < 2.2$ and full azimuth. There are no PHENIX measurements for J/ψ reference data in $p + p$ collisions at these energies since there is no run in 39 GeV $p + p$ and only a limited dataset was previously collected at 62.4 GeV $p + p$ collisions, which could not provide a reasonable baseline for J/ψ . Hence a compilation of the measurements from other experiments in addition to a theoretical estimate (Color Evaporation Model by R. Vogt) were used to make a best estimate for the baseline cross-section. The details can be found in [5].

Figure 3 (right) shows the J/ψ suppression at forward rapidities at all three energies as a function of 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 are the cumulative effect of the different competing physics processes. However the strength of these processes remain unclear without detailed understanding of the production of J/ψ in nuclear target, termed cold nuclear matter 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 new theory calculation which includes cold nuclear matter effects, regeneration and QGP suppression for the J/ψ suppression at forward rapidity is compared to the data in figure 3 (left). The contribution of direct J/ψ and regeneration are shown separately. It appears that the QGP suppression decreases while going from 200 GeV to 39 GeV as seen in the direct component but there will be a strong regeneration effect at higher energies due to higher number of $c\bar{c}$ pairs. The regeneration contribution is expected to the increase with collision energy due to the increase in the total number of charm pairs produced. The inclusion of the regeneration

component resulted in a similar suppression at all the energies and PHENIX measurements are consistent with the theoretical calculations within the global systematic uncertainties.

4. Summary

The PHENIX experiment has measured both π^0 and J/ψ production at $\sqrt{s_{NN}} = 39$ and 62.4 GeV $Au + Au$ collisions. Using suitable $p + p$ reference estimates from other experiments and theory calculations when our own measurements are not available, R_{AA} was calculated and compared with our earlier 200 GeV measurements. The observed π^0 production is strongly suppressed in most central collisions at all energies but the suppression gets weaker at lower energies in the moderate p_T region. The J/ψ R_{AA} results are similar to that measured in 200 GeV with slightly less suppression at these lower energies. The J/ψ results are consistent with the theoretical calculation which shows a balance in effects of more QGP suppression as well as more regeneration at higher energy collisions.

References

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