Excess of J/ψ Production at Very Low Transverse Momenta in A+A Collisions from STAR

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A significant excess of J/ψ yield at very low transverse momentum ($p_T < 0.3$ GeV/c) has been observed by the ALICE Collaboration in peripheral Pb+Pb collisions, which points to evidence of coherent photoproduction of J/ψ in violent hadronic interactions. The survival of photoproduced J/ψ merits more experimental investigations. In this article, we report on the STAR measurements of J/ψ production at very low transverse momenta (p_T) in hadronic Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV at mid-rapidity. Centrality dependence of J/ψ yields and nuclear modification factors at very low p_T are presented.

Keywords: Relativistic heavy-ion collisions; J/ψ ; coherent photoproduction.

1. Introduction

The Relativistic Heavy Ion Collider (RHIC) is built to search for the Quark-Gluon Plasma (QGP) and to study its properties in laboratory through high energy heavy-ion collisions¹. J/ψ suppression in hadronic heavy-ion collisions, due to color screening of quark-antiquark potential in the deconfined medium, has been proposed as a signature of the QGP formation². Other mechanisms, such as the cold nuclear matter (CNM) effects^{3,4} and charm quark recombination⁵, are likely to contribute to the observed modification of J/ψ production in hadronic heavy-ion collisions. At present, the interplay of color screening, regeneration and CNM effects can reasonably describe the J/ψ suppression from SPS to LHC in heavy-ion collisions⁶.

The J/ψ can also be produced via the strong electromagnetic fields generated by heavy ions, e.g. photon-nucleus coherent or incoherent interactions⁷, in ultra-relativistic heavy-ion collisions. This has been studied in detail in ultra-peripheral

collisions (UPC), where the impact parameter can reach several tens of femtometers and no hadronic interactions occur.

Interestingly, a significant excess of J/ψ yield at very low transverse momenta ($p_T < 0.3$ GeV/c) has been observed by the ALICE collaboration in peripheral hadronic Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at forward-rapidity⁸, which cannot be explained by the hadronic J/ψ production modified by the cold or hot medium effects. The observed excess may originate from the coherent photon-nucleus interactions^{9,10,11}, which would be very challenging for the existing models. Measurements of J/ψ production at very low p_T in different collision energies, collision systems, and collision geometries can shed new lights on the origin of the excess.

In this article, we report on the STAR measurements of J/ψ production at very low p_T in hadronic Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV at mid-rapidity. Centrality dependence of J/ψ yields and nuclear modification factors at very low p_T are presented.

2. Experiment and Analysis

The STAR experiment is a large-acceptance multi-purpose detector which covers full azimuth angle at pseudorapidity of $|\eta| < 1$ ¹². The Au+Au and U+U data were recorded using a minimum-bias trigger which requires coincidence signals in the Vertex Position Detector (VPD) and the Zero Degree Calorimeter (ZDC). In this analysis, the J/ψ 's are reconstructed through their decays into electron-positron pairs, $J/\psi \rightarrow e^+ + e^-$ (branching ratio equal to $5.97 \pm 0.03\%$ ¹³). The primary detectors used in this analysis are the Time Projection Chamber (TPC)¹⁴, the Time-of-Flight (TOF) detector¹⁵, and the Barrel Electromagnetic Calorimeter (BEMC)¹⁶. The electron identification and J/ψ reconstruction techniques are similar to those described in Ref.^{17,18}.

3. Result

Figure 1 shows the J/ψ invariant yields in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV as a function of p_T for different centralities at mid-rapidity ($|y| < 1$). The error bars depict the statistical errors while the boxes represent the systematic uncertainties. The solid lines in the figure are the fits to data points in the range of $p_T > 0.2$ GeV/c using:

$$\frac{d^2N}{2\pi p_T dp_T dy} = a \times \frac{1}{(1 + b^2 p_T^2)^n} \quad (1)$$

wherein a , b , and n are free parameters. The dashed lines are the extrapolations of the fits. As shown in the figure, the fits describe the data above 0.2 GeV/c very well, but significantly underestimate the yield below 0.1 GeV/c for all three centrality bins.

The extracted J/ψ R_{AA} as a function of p_T in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV for different centrality classes

Fig. 1. (color online) J/ψ invariant yield for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV as a function of p_T for different centralities at mid-rapidity.

Fig. 2. (color online) The extracted J/ψ R_{AA} as a function of p_T in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV for different centrality classes.

are shown in Fig 2. The p+p baselines used for R_{AA} calculations are derived from Ref. ¹⁹. A significant excess of the J/ψ yield in the p_T range of 0-0.1 GeV/c is observed for peripheral collisions (40-80%). The kinematic range of the enhancement is consistent with that of coherent photon-nucleus interactions, which indicates that the excess may originate from the coherent production.

Assuming that the coherent photoproduction causes the excess at very low p_T , the J/ψ yield as a function of the momentum transfer squared t ($t = p_T^2$) for 40-80% Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV is shown in Fig. 3. The structure of the distribution is very similar to that observed in UPC ²⁰. An exponential fit is applied

Fig. 3. (color online) Measurements of J/ψ invariant yield as a function of the momentum transfer squared t for 40-80% Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

to the distribution in the t range of 0.002 - 0.015 $(\text{GeV}/c)^2$, and the extracted slope parameter is 196 ± 31 $(\text{GeV}/c)^{-2}$, which is consistent with that of a Au nucleus (199 $(\text{GeV}/c)^{-2}$). As shown in the figure, the data point at the lowest t value is lower than the extrapolation of the exponential fit, which may be an indication of an interference. The theoretical calculation with the interference for the UPC ²¹, shown as the blue curve in Fig. 5, can describe the data very well ($\chi^2/NDF = 4.9/4$) for $t < 0.015$ $(\text{GeV}/c)^{-2}$.

Fig. 4. (color online) The p_T integrated J/ψ yields ($p_T < 0.1$ GeV/c) as a function of N_{part} for 30-80% Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The expectation of hadronic production (scaled by a factor of 5) is also shown for comparison.

Figure 4 shows the p_T -integrated J/ψ yields ($p_T < 0.1$ GeV/c) as a function of N_{part} for 30-80% Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The integrated J/ψ yields show no significant centrality dependence. This is beyond the expectation from hadronic production, which, scaled by a factor of 5, is also plotted for comparison. As depicted in the figure, the contribution of hadronic production is not dominant in the excess range, especially in peripheral collisions. The integrated J/ψ yields within the same p_T range in U+U collisions are similar to those in Au+Au collisions.

4. Summary

In summary, we report the recent STAR measurements of J/ψ production at very low p_T in hadronic Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV at mid-rapidity. Centrality dependence of J/ψ yields and nuclear modification factors, as well as dN/dt distributions at very low p_T are reported. A significant excess of J/ψ yield at p_T interval 0-0.1 GeV/c is observed for peripheral collisions (40-80%). The excess for 30-80% centrality range shows no significant centrality dependence within uncertainties, which is beyond the expectation from the hadronic production. The characteristics of the excess are consistent with coherent photon-nucleus interactions.

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