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J/ψ production in U+U collisions at the STAR experiment

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Quark-gluon plasma (QGP), a novel state of deconfined nuclear matter, has been studied in high-energy heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC). Due to the color screening of the quark-antiquark potential in the QGP production of heavy quarkonia (e.g. J/ψ, Υ) is expected to be suppressed. However, there are also other effects that may influence the observed quarkonium yields (e.g. secondary production in the QGP, cold-nuclear-matter effects). To understand those effects we need to study production of heavy quarkonia in various colliding systems. We present preliminary results on nuclear modification factor of J/ψ production at mid-rapidity via the di-electron decay channel in minimum-bias U+U collisions at $\sqrt{s_{\rm NN}} = 193$ GeV at the STAR experiment and the current status of analysis of J/ψ production in central U+U collisions.

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PoS(EPS-HEP2015)204

1. Introduction

Measurements of heavy quarkonium production in heavy-ion collisions are used to study properties of the QGP. Heavy quarkonium production is expected to be suppressed in the presence of the QGP compared to production in proton+proton (p+p) collisions due to the color screening of the quark-antiquark potential in the deconfined medium. This phenomenon has long been considered as one of the most prominent signatures of the QGP [1].

However, there are other effects that may modify the observed suppression such as cold-nuclear-matter effects, feed down effects, secondary production via coalescence of charm quarks. To understand these different mechanisms it is important to study the heavy quarkonium production in different collisional systems and at different collision energies and centralities.

Modification of heavy quarkonium production in nucleus+nucleus collisions (A+A) compared with p+p collisions is usually quantified by the so-called nuclear modification factor $R_{\rm AA}$:

$$R_{\rm AA}(y, p_{\rm T}) = \frac{1}{< N_{\rm bin} >} \frac{d^2N_{\rm AA}/{\rm d}p_{\rm T}{\rm d}y}{d^2N_{\rm pp}/{\rm d}p_{\rm T}{\rm d}y}. \tag{1.1}$$

It is defined as the ratio of the number of particles produced in A+A collisions to the number of particles produced in p+p collisions scaled by the average number of binary nucleon-nucleon collisions $< N_{\rm bin} >$. With no medium effect the yield of heavy quarkonia in heavy-ion collisions should scale with the number of elementary binary collisions and resulting $R_{\rm AA}$ should be equal to unity. As it turns out the medium produced in heavy-ion collisions can modify this scaling resulting in the effect of suppression $R_{\rm AA} < 1$ or enhancement $R_{\rm AA} > 1$.

At the STAR experiment, effects of the hot medium on J/ψ production have been studied in Au+Au collisions at $\sqrt{s_{\rm NN}} = 39,\ 62.4,\ 200$ GeV [2, 3, 4]. STAR has also collected data on U+U collisions at $\sqrt{s_{\rm NN}} = 193$ GeV. Since U nuclei are larger than Au nuclei, it is expected that in the U+U collisions the energy density of the created medium is higher than in Au+Au collisions [5]. This applies particularly for the most central U+U collisions in which the achievable energy density is expected to be up to $\sim 20\%$ larger relative to Au+Au collisions. Thus they allow for further testing of the color screening hypothesis [5].

2. Data analysis in U+U collisions

The Solenoidal Tracker at RHIC (STAR) [6] is a multi-purpose detector composed of various subsystems. It excels in tracking and identification of charged particles at mid-rapidity and with full coverage in azimuth.

At the STAR experiment, heavy quarkonia have been studied via their di-electron decay channels, e.g. $J/\psi \rightarrow e^+e^-$ with a branching ratio $B_{\rm ee} = 5.9$ %. In the analyses presented here the STAR Time Projection Chamber (TPC) [7], Time of Flight (TOF) [8] detector and Barrel Electromagnetic Calorimeter (BEMC) [9] are used for electron identification. The TPC is the main tracking device of STAR and provides particle identification via their specific energy loss dE/dx, the TOF detector measures $1/\beta$ of the particles and together with TPC enables separation of electrons from hadrons up to 1.4 GeV/c. The BEMC measures energies of electromagnetic showers produced by high-$p_{\rm T}$ particles and enables electron-hadron separation by pc/E cut, where E is the energy deposited in the BEMC and p is the momentum of the track. For electron candidates $pc/E \sim 1$ while for hadrons $pc/E > 1$. It is also used to trigger on high-p_T electrons. This is called the High Tower (HT) trigger. Minimum bias (MB) data are triggered by the Vertex Position Detectors (VPD) and the 0-5% central data are triggered by Zero Degree Calorimeters based on measured energy of spectator neutrons combined with track multiplicity information from TOF.

3. R_{AA} in minimum bias U+U collisions

To quantify the hot medium effects on J/ψ production, nuclear modification factor in minimum bias Au+Au and U+U collisions has been measured [2, 3, 4]. Figure 1 (left panel) shows the nuclear modification factor in minimum bias and HT triggered U+U collisions [2]. R_{AA} as a function of p_T is similar to that observed in Au+Au at $\sqrt{s_{NN}} = 200$ GeV [2]. In the right panel of Figure 1 the nuclear modification factor of J/ψ is presented as a function of the number of nucleons participating in collision N_{part}. Results are shown for different colliding energies $\sqrt{s_{NN}} = 200$ (black), 62.4 (red) and 39 (blue points) GeV in Au+Au collisions [2] and for $\sqrt{s_{NN}} = 193$ GeV in minimum bias U+U collisions. U+U data is consistent with Au+Au results with similar N_{part}, within errors.

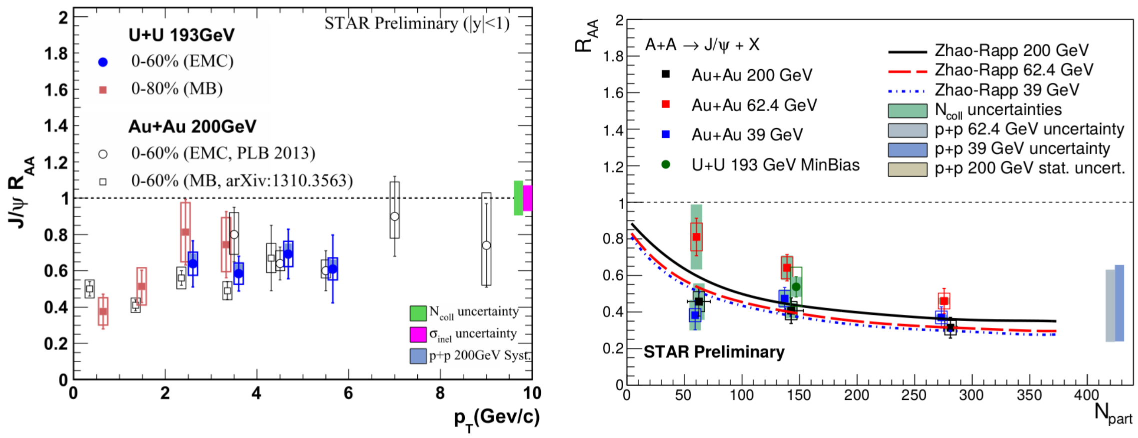

Figure 1: Left:J/ψ R_{AA} as a function of p_T in minimum bias and HT triggered Au+Au and U+U collisions [2]. Right: J/ψ R_{AA} as a function of N_{part} in Au+Au collisions at $\sqrt{s_{NN}} = 200$ (black), 62.4 (red) and 39 (blue points) GeV [2] and compared with model predictions [10] and in minimum bias U+U collisions at $\sqrt{s_{NN}} = 193$ GeV.

4. Analysis status of 0-5% most central U+U collisions

In the analysis presented here 115 M of 0-5% most central U+U collisions collected in 2012 at $\sqrt{s_{NN}} = 193$ GeV were used. J/ψ signal was reconstructed via the di-electron decay channel ($J/\psi \to e^+e^-$). Electron candidates were selected from tracks with transverse momenta $p_T >$ 1.0 GeV/c which satisfied selection criteria on TPC, TOF and BEMC signals: $n\sigma_e^{TPC}$, the difference from the expected ln (dE/dx) for electrons expressed in terms of standard deviation units, was required to be in the range (-1.5, 2.0) for all electron candidates. For particles with momenta

PoS(EPS-HEP2015)204

$p < 1.4$ GeV$/c$ we required $0.970 < 1/\beta^{\mathrm{TOF}} < 1.025$, for $p > 1.4$ GeV$/c$ the energy E deposited in the BEMC tower had to be larger than 0.15 GeV and the ratio pc/E^{BEMC} to be in the range (0.7, 2.0). The cut on $1/\beta^{\mathrm{TOF}}$ for $p > 1.4$ GeV$/c$ was used if particles had a signal in TOF. Figure 2 shows $1/\beta^{\mathrm{TOF}}$ and $n\sigma_{\mathrm{e}}^{\mathrm{TPC}}$ distributions and application of corresponding cuts.

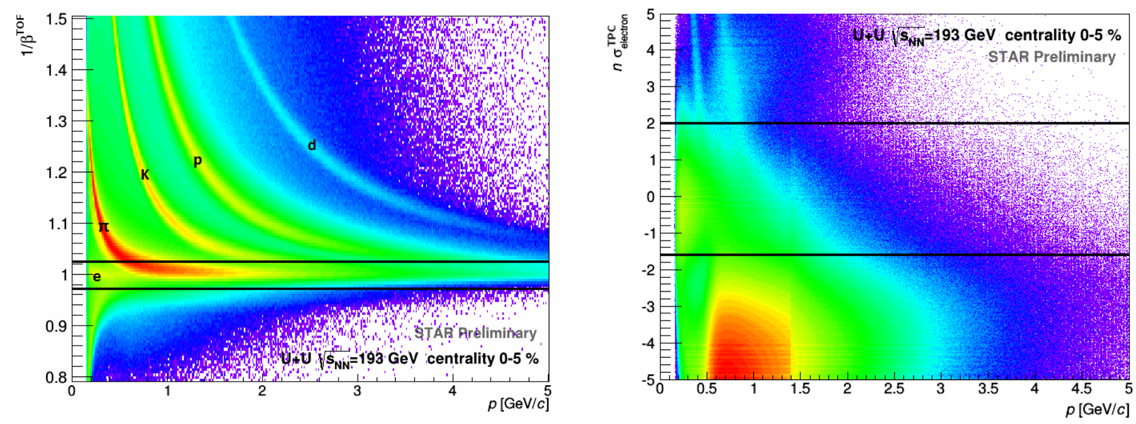

Figure 2: Left: $1/\beta^{\mathrm{TOF}}$ of particles with depicted cut for electron candidates (black lines). Right: $n\sigma_{\mathrm{e}}^{\mathrm{TPC}}$ of particles satisfying TOF and BEMC cuts. Black lines denote the $n\sigma_{e}^{\mathrm{TPC}}$ cut.

Combinatorial background of the J/ψ signal was estimated by the mixed-event background method. Left panel of Figure 3 shows signal before the combinatorial background subtraction. After the combinatorial background subtraction the invariant mass distribution of di-electron pairs was fitted with a crystal ball function to describe the signal while the residual background was fitted with a linear function. The right panel of Figure 3 shows signal after combinatorial background subtraction and fits for the signal and the background. The J/ψ yield calculated by the bin counting method in the invariant mass region (2.9, 3.2) GeV/c^2 was 4960 ± 580 with a significance of 8.6 σ.

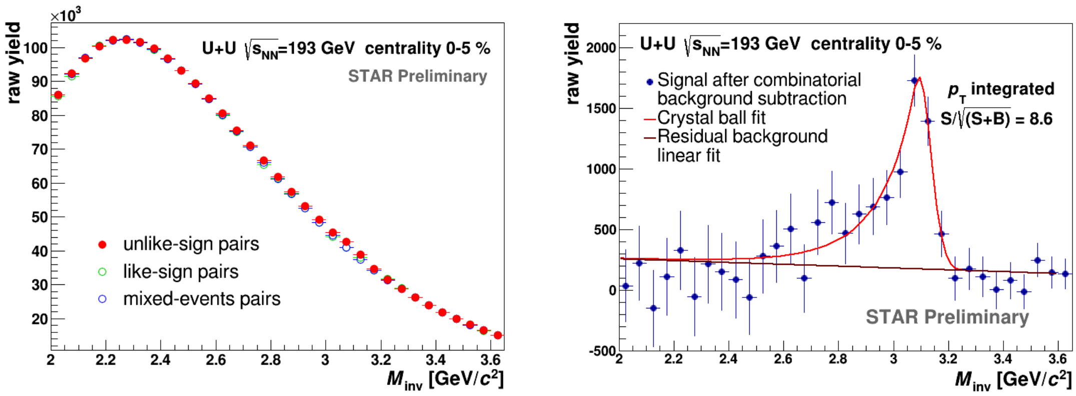

Figure 3: Left: Invariant mass spectra of unlike-sign, like-sign and mixed-event electron pairs. Right: J/ψ signal after combinatorial background subtraction fitted with a crystal ball function together with a linear function used to describe the residual background.

5. Summary

In this work we have presented preliminary results on nuclear modification factor for J/ψ production in minimum-bias U+U collisions at $\sqrt{s_{\rm NN}} = 193$ GeV at the STAR experiment and the current status of J/ψ production analysis in 0-5% most central U+U collisions. Suppression of J/ψ production in minimum-bias U+U collisions is similar to that observed in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions. In 0-5% most central U+U collisions a strong signal of J/ψ of significance 8.6 σ has been observed.

Data analysis leading to the extraction of J/ψ nuclear modification factor in 0-5% most central U+U collisions is underway. Results of this analysis will extend our knowledge about J/ψ production modification in U+U collisions at the highest achievable energy density at RHIC and enable us to better understand interactions of J/ψ with hot and dense nuclear matter.

Acknowledgments

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