

Overview of quarkonium production studies at the STAR experiment

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Abstract. Quarkonium states can be used to study the properties of the quark-gluon plasma created in heavy-ion collisions. However, Cold Nuclear Matter (CNM) effects need to be taken into account when interpreting the quarkonium suppression observed in these collisions. In addition, the quarkonium production mechanism in elementary collisions need to be better understood. These proceedings contains an overview of recent quarkonium measurements with the STAR experiment. A comprehensive study of both J/ψ and Υ production is performed in different colliding systems (p+p, p+Au, Au+Au).

1. Introduction

Quarkonium states like J/ψ or Υ are important probes of quark-gluon plasma properties. They are expected to dissociate at high temperature due to Debye-like screening of color charges [1]. A bound state dissociates if its radius is larger than the Debye screening radius ($r > r_{Debye}$). As the temperature increases, the $r_{Debye} \propto T^{-1}$ decreases. Since each quarkonium state has a different radius and binding energy, a sequential suppression is expected, where more tightly bound states dissociate at higher temperatures than the less strongly bound ones. Such a suppression has already been observed at SPS for J/ψ [2] and at RHIC and LHC for J/ψ [3] and Υ [4, 5]. However, the observed suppression may have contribution from a combination of other effects, which complicate the interpretation. In addition, there is a contribution of feed-down from excited quarkonium states. Part of the suppression may be due to cold nuclear matter effects like nuclear absorption, interactions with comovers or modification of parton distributions in nucleons inside nuclei compared to free nucleons. These bound nucleons exhibit phenomena like shadowing and anti-shadowing and are included in the nuclear parton distribution functions - nPDFs, which are modified with respect to free nucleon PDFs. Moreover, the quarkonium production mechanism in elementary proton-proton collisions needs to be fully understood in order to draw firm conclusions.

It is then of importance to perform differential studies of the quarkonia production under varying conditions such as different colliding species and different collision energies and kinematic regions.

2. Quarkonium studies at the STAR experiment

At the STAR experiment reconstruction of quarkonium states is done in both dielectron and dimuon channels. In the dielectron channel, STAR uses Time Projection Chamber (TPC)

for tracking and particle identification and Barrel Electromagnetic Calorimeter for electron identification and triggering on high- p_T electrons. In addition, Time of Flight (TOF) is used for particle identification. These detectors have acceptance of $|\eta| < 1$ and allow to measure quarkonium production at mid-rapidity within $|y| < 1$. In the dimuon channel TPC and TOF are also used along with Muon Telescope Detector (MTD), which uses STAR magnet as an absorber. MTD is used for triggering and muon identification and has an acceptance of 45% in ϕ for $|\eta| < 0.5$.

3. Quarkonium production in p+p collisions

Studies of quarkonium production in p+p collisions are necessary as a reference for $p + A$ and $A + A$ collisions. Also, they allow to study the quarkonium production mechanism. STAR has measured both J/ψ and Υ production cross sections in p+p collisions at $\sqrt{s} = 200, 500$ and 510 GeV [6, 7]. Fig. 1 shows inclusive J/ψ production cross section vs. p_T measured at $\sqrt{s} = 500$, and 510 GeV [7]. In Fig. 2 are shown the results relative to the Levy fit together with comparison to model calculations, to which $B \rightarrow J/\psi$ feed-down contribution using a FONLL calculation [8, 9] was added to have a fair comparison. Inclusive Υ production cross sections vs. p_T for combined Υ states and separately for $\Upsilon(1S)$ and $\Upsilon(2S + 3S)$ measured at $\sqrt{s} = 500$ GeV are shown in Fig. 3. These are also compared to model predictions.

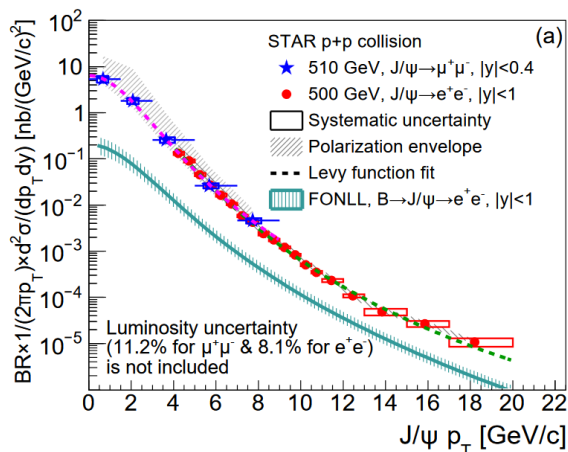


Figure 1. Cross section for inclusive J/ψ production vs. p_T measured in p+p collisions at $\sqrt{s} = 500$ GeV and $\sqrt{s} = 510$ GeV [7] fitted with a Levy function (dashed line) shown along with $B \rightarrow J/\psi$ feed-down contribution based on FONLL calculation (teal line).

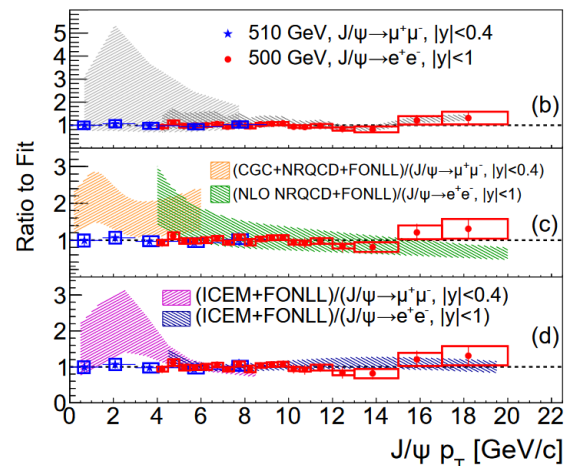


Figure 2. Ratio of the J/ψ cross section from Fig. 1 [7] to the Levy fit compared to CGC+NRQCD [10] and NLO NRQCD as well as ICeM model [11] calculations. All model calculations include the $B \rightarrow J/\psi$ feed-down contribution.

In general, quarkonium production is reasonably described by the Color Evaporation Model [12] (CEM) or Improved CEM [11]. The NLO Non-relativistic QCD calculation [13] (NRQCD) also describes the measurements for $p_T > 4$ GeV/c. When coupled with Color Glass Condensate [10] (CGC+NRQCD) initial conditions, the description is on the edge of uncertainties and even much above for Υ , in the low- p_T region.

Studies of quarkonium production as a function of charged particle multiplicity may provide information about the production mechanism of quarkonium relative to soft particles. Normalized quarkonium production $\frac{N_x}{\langle N_x \rangle}$ is also measured as a function of normalized charged particle multiplicity $\frac{N_{ch}}{\langle N_{ch} \rangle}$. STAR results are shown in Fig. 4 and compared to measurements at

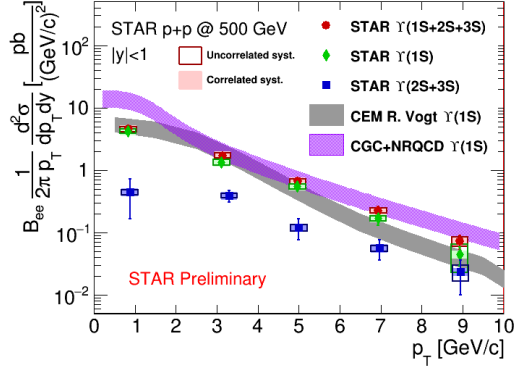


Figure 3. Inclusive cross section of combined $\Upsilon(1S + 2S + 3S)$, $\Upsilon(1S)$ and $\Upsilon(2S + 3S)$ vs. p_T compared to CGC+NRQCD [10, 14] and CEM model [15] calculations.

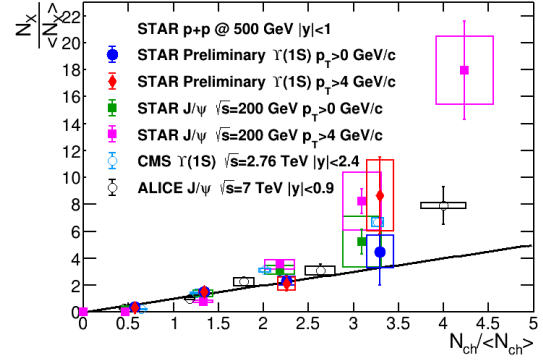


Figure 4. Normalized yield $\frac{N_x}{\langle N_x \rangle}$ vs. normalized charged particle multiplicity $\frac{N_{ch}}{\langle N_{ch} \rangle}$ for $\Upsilon(1S)$ and J/ψ [6] measured by STAR compared to $\Upsilon(1S)$ by CMS [16] and J/ψ from ALICE [17]. The line corresponds to linear increase $\frac{N_x}{\langle N_x \rangle} = \frac{N_{ch}}{\langle N_{ch} \rangle}$.

LHC. A similar, faster than linearly increasing, trend is observed for both J/ψ and Υ at RHIC and LHC.

4. Quarkonium production in p+A collisions at $\sqrt{s_{NN}} = 200$ GeV

Nuclear modification factor R_{pAu} has been measured for J/ψ and Υ in p+Au at $\sqrt{s_{NN}} = 200$ GeV. The $R_{pA}(R_{dAu})$ for Υ is shown in Fig. 5 and compared to production models incorporating nPDF [18] or energy loss or both [19] effects. The new STAR results have much improved precision over the previous measurement [4] and provide an indication for Υ suppression in p+Au collisions. The new STAR data are systematically below the model predictions, however on the edge of combined uncertainties.

5. Quarkonium production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

STAR has recently measured J/ψ production in the dimuon channel [21]. The nuclear modification factor R_{AA} vs. N_{part} is shown in Fig. 6 along with PHENIX and ALICE measurements and Rapp's [22] (TAMU) and Tsinghua group calculations [24, 25]. The first model uses in-medium binding energies of J/ψ using T-matrix calculations and includes both regeneration and CNM effects. The latter model describes the J/ψ behavior in the medium using transport equations and includes regeneration, while neglecting CNM effects. Calculations based on Statistical Hadronization Model (SHM) [23] are also shown.

STAR new results on $\Upsilon(1S)$ and $\Upsilon(2S + 3S)$ production in dielectron and dimuon channels have been combined for increased precision and are compared to Rothkopf's [26] and Rapp's [27] models in Fig. 7 and Fig. 8 respectively. The Rothkopf's model describes the behavior of Υ in the QGP medium using potentials from lattice QCD calculations. This model does not take into account the CNM effects and regeneration. Both models describe the data, with the exception of $\Upsilon(2S + 3S)$ for 30 – 60% centrality for Rothkopf's model.

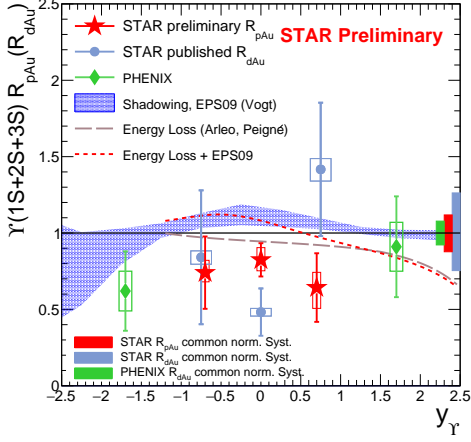


Figure 5. Nuclear modification factor R_{pAu} (R_{dAu}) vs. rapidity y . STAR Υ data in p+Au and d+Au collisions [4] are compared to PHENIX data [20] and model predictions including nPDF [18] and energy loss with nPDF [19] effects.

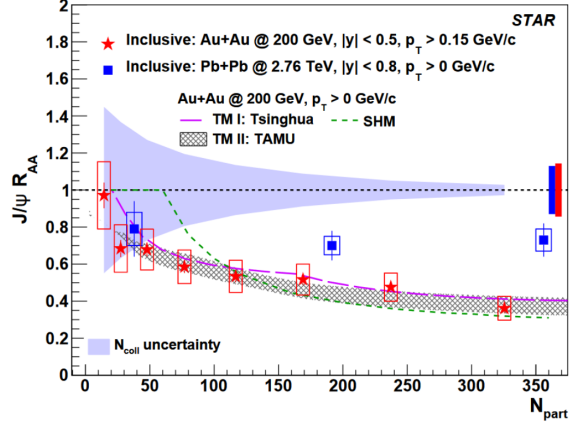


Figure 6. Nuclear modification factor R_{AA} vs. N_{part} for J/ψ measured by STAR [21] and ALICE compared to Rapp's model calculation (TAMU) [22], Statistical Hadronization Model (SHM) [23] and Tsinghua Model [24, 25].

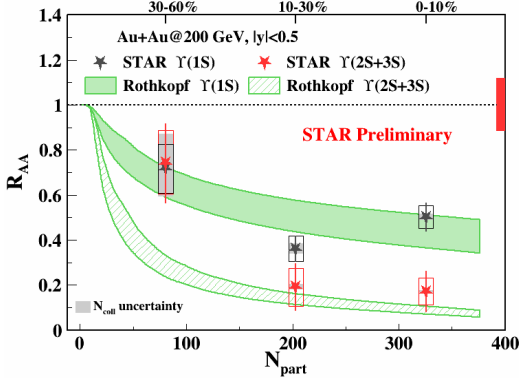


Figure 7. Nuclear modification factor vs. number of participant nucleons N_{part} for $\Upsilon(1S)$ and $\Upsilon(2S + 3S)$ compared to Rothkopf's model [26].

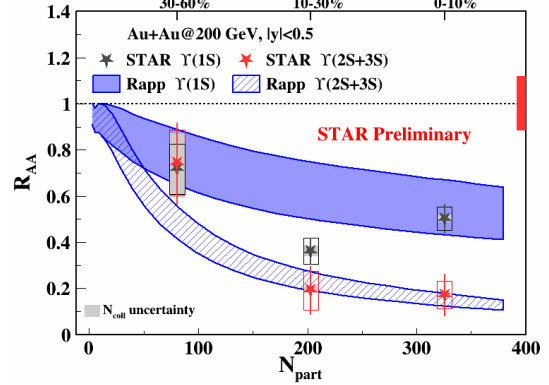


Figure 8. Nuclear modification factor vs. N_{part} as in Fig. 7 compared to Rapp's model calculation [27].

6. Conclusions

STAR has performed a comprehensive study of J/ψ and Υ production in different colliding systems (p+p, p+Au, Au+Au) and at different energies in case of p+p: $\sqrt{s} = 200, 500,$ and 510 GeV . The data have been compared to relevant production models. Quarkonium production in p+p collisions can be well described by the CEM, ICEM and NLO NRQCD calculations, however CGC+NRQCD calculations are above the data at low- p_T . In p+Au collisions an indication of Υ suppression is observed and the R_{pAu} is overestimated by the models, however on the edge of combined uncertainties. STAR results for both J/ψ and Υ R_{AA} are well described by all the model calculations: Rapp's, SHM and Tsinghua models for J/ψ and Rapp's and Rothkopf's for Υ . The only exception is for $\Upsilon(2S+3S)$ for 30–60% centrality, where Rothkopf's model underestimates the data.

Acknowledgements

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