Recent results of Υ production measured with the STAR experiment

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INTRODUCTION

Upsilon (Υ) mesons are a good tool to study the nature of strong interaction and properties of quark-gluon plasma (QGP), created in ultra relativistic heavy-ion collisions [1]. Measurements of the production of these mesons in p+p collisions provide information about the quarkonium production mechanism. Such measurements serve also as a reference for studies of QGP, where Υ and J/ψ mesons are expected to dissociate at high temperatures [2] resulting in suppressed yields observed in heavy-ion collisions. This effect is due to Debye-like screening of color charges, which causes the bound states to dissociate. The level of suppression is estimated by measuring the nuclear modification factor:

$$R_{\mathrm{AA}} = \frac{1}{\langle N_{\mathrm{coll}} \rangle} \frac{\mathrm{d}^2 N_{A+A}/\mathrm{d}p_T \mathrm{d}y}{\mathrm{d}^2 N_{p+p}/\mathrm{d}p_T \mathrm{d}y} \tag{1}$$

where $\langle N_{\mathrm{coll}} \rangle$ is the mean number of nucleon+nucleon collisions and the numerator and the denominator are differential yields vs. transverse momentum (p_T) and rapidity (y) in A+A and p+p collisions, respectively. Moreover, each of $\Upsilon(nS)$ has a different binding energy and dissociates at a different temperature, leading to a sequential suppression [3]. The measured Υ yields are also affected by feed-down contributions from heavier states, such as $\Upsilon(nS) \rightarrow \Upsilon(1S)\pi^+\pi^-$, $\chi_{bJ}(nS) \rightarrow \Upsilon(1S)\gamma$ and similar decays.

Furthermore, in A+A collisons there may be a contribution from a number of Cold Nuclear Matter (CNM) effects, which are unrelated to QGP. These effects include absorption in nucleus, comover interactions [4], coherent partonic energy loss [5], and modification of the nuclear parton distribution functions with respect to those of free nucleons. The last one shows shadowing and anti-shadowing effects [6], which could decrease or increase the parton (gluon) densities. All the above effects can be studied using p+A or d+A collisons.

Finally, studies of normalized yield $\Upsilon/\langle\Upsilon\rangle$ dependence on normalized charged particle multiplicity $N_{ch}/\langle N_{ch}\rangle$ allow to investigate interplay between hard and soft processes in high-N_{ch} p+p events. These studies have been performed by the CMS experiment at the LHC [7].

PRODUCTION IN P+P COLLISIONS

The STAR experiment has measured Υ production cross section in p+p collisions at $\sqrt{s}$ = 200 GeV vs. rapidity (y) and $\sqrt{s}$ = 500 GeV vs. p_T and y. Figure 1 shows the $\Upsilon(nS)$ rapidity-differential cross section in p+p collisions at $\sqrt{s}$ = 500 GeV, where the newly measured $\Upsilon(2S)$ and $\Upsilon(3S)$ cross sections are presented along with $\Upsilon(1S)$. The $\Upsilon(1S)$ data are well described by Color Evaporation Model (CEM) [8] calculations for inclusive $\Upsilon(1S)$. The same data are overestimated by a CGC+NRQCD [9, 10] calculation for directly produced $\Upsilon(1S)$.

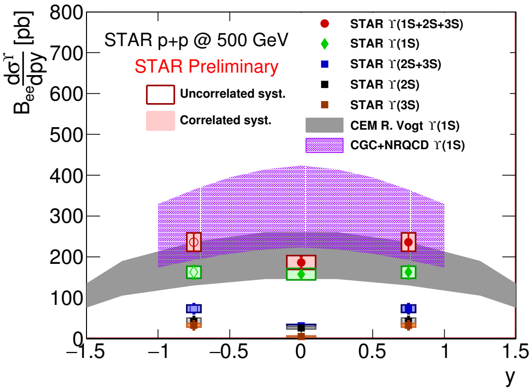

Fig. 1. $\Upsilon(nS)$ cross sections vs. rapidity (y) in p+p collisions at $\sqrt{s}$ = 500 GeV, compared to model predictions for $\Upsilon(1S)$ [8, 9, 10].

The dependence of normalized $\Upsilon(1S)/\langle\Upsilon(1S)\rangle$ yield on normalized $N_{ch}/\langle N_{ch}\rangle$ was measured by STAR in p+p collisions at $\sqrt{s}$ = 500 GeV. This is presented in Fig. 2 and compared to STAR J/ψ results at $\sqrt{s}$ = 200 GeV [11], CMS $\Upsilon(1S)$ data [7], and ALICE data for J/ψ [12]. Both the Υ and J/ψ data follow similar trends at RHIC and the LHC, despite a large difference in the collision energies.

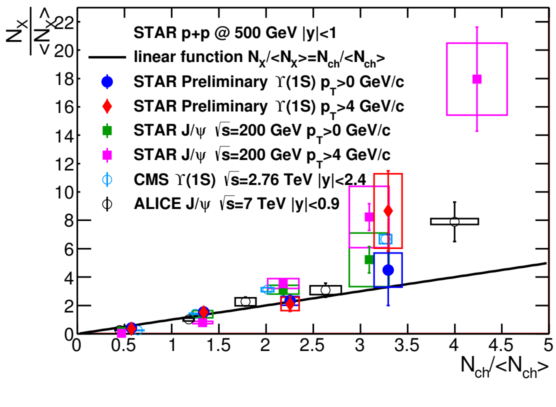

Fig. 2. Normalized yield $\Upsilon(1S)/\langle\Upsilon(1S)\rangle$ vs. normalized charged particle multiplicity $N_{ch}/\langle N_{ch}\rangle$. STAR results for $\Upsilon(1S)$ and J/ψ are compared to ALICE [12] and CMS [7] measurements.

SUPPRESSION IN AU+AU COLLISIONS

In Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV, the Υ R_{AA} is obtained by combining measurements in $\Upsilon \rightarrow e^+e^-$ and $\Upsilon \rightarrow \mu^+\mu^-$ decay channels. The resulting

R_{AA} of $\Upsilon(1S)$ vs. number of nucleons participating in a collision (a measure of centrality) N_{part} is shown in Fig. 3 along with the CMS data [13]. These results are compared to a model calculation [14], which includes QGP effects as well as regeneration and CNM effects.

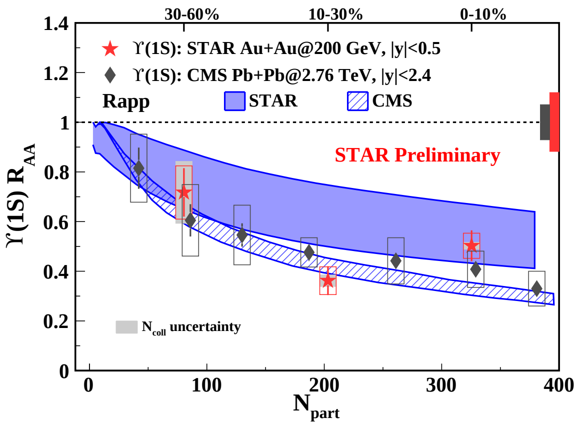

Fig. 3. Nuclear modification factor R_{AA} of $\Upsilon(1S)$ vs. number of participating nucleons N_{part}. The STAR data are compared to CMS results [13] and a model calculation [14].

The R_{AA} of $\Upsilon(2S{+}3S)$ is shown in Fig. 4 and compared to $\Upsilon(2S)$ measurements by CMS [13] as well as calculations by the same model [14].

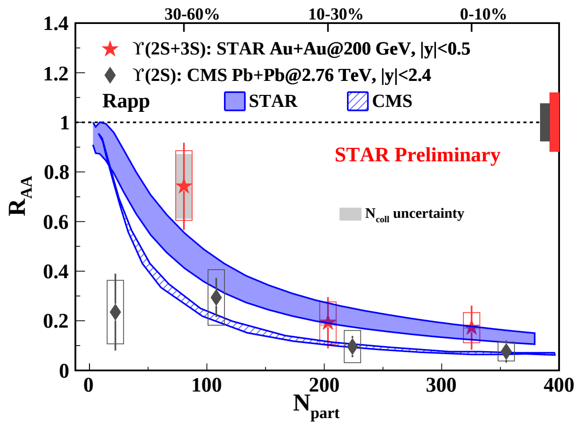

Fig. 4. Nuclear modification factor R_{AA} of $\Upsilon(2S{+}3S)$ vs. N_{part}. The STAR data are compared to CMS results for $\Upsilon(2S)$ [13] as well as a model calculation [14].

CONCLUSIONS

STAR experiment has measured Υ production in p+p collisions at $\sqrt{s}$ = 200 GeV and $\sqrt{s}$ = 500 GeV. The $\Upsilon(1S)$ data are well described by CEM model calculation [8] for inclusive $\Upsilon(1S)$, while overestimated by CGC+NRQCD model [9, 10] for direct $\Upsilon(1S)$. The charged particle multiplicity N_{ch} dependence was also studied, by measuring normalized $\Upsilon(1S)/\langle\Upsilon(1S)\rangle$ yield vs. $N_{ch}/\langle N_{ch}\rangle$. Similar trend is observed for $\Upsilon(1S)$ and J/ψ at RHIC and LHC experiments. This suggests similar phenomena happen for these particles even at different collision energies.

In Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, the Υ production is measured both in dielectron and dimuon decay channels and the results are combined for better precision R_{AA} calculation. Both R_{AA} of $\Upsilon(1S)$ and $\Upsilon(2S{+}3S)$ is measured vs. number of participant nucleons N_{part}. The $\Upsilon(1S)$ data show a similar level of suppression at STAR and CMS, despite higher medium temperature reached at CMS. This could point to regeneration or CNM effects playing a role, and better constraints on these effects are needed. It should be also noted that most likely a large fraction of the observed suppression is due to the suppression of the feed-down contributions from the excited states. In central Au+Au collisions, $\Upsilon(2S{+}3S)$ R_{AA} is smaller than that of $\Upsilon(1S)$, consistent with the expectation of the sequential suppression. The $\Upsilon(2S{+}3S)$ data indicate a smaller suppression at RHIC than at LHC in peripheral collisions. All these data are qualitatively described by a model calculation [14], which includes the effects of Debye-like screening of color charges in hydrodynamic-modeled QGP with addition of regeneration and CNM effects.

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