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Υ Production in Heavy-Ion Collisions from the STAR Experiment

Zaochen Ye for the STAR Collaboration

University of Illinois at Chicago, Chicago, Illinois, 60607, USA

Abstract

In these proceedings, we present recent results of Υ measurements in heavy-ion collisions from the STAR experiment at RHIC. Nuclear modification factors (R_{AA}) for $\Upsilon(1S)$ and $\Upsilon(1S+2S+3S)$ in U+U collisions at $\sqrt{s_{\rm NN}}$ = 193 GeV are measured through the di-electron channel and compared to those in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV and Pb+Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. The ratio between the $\Upsilon(2S+3S)$ and $\Upsilon(1S)$ yields in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV is measured in the di-muon channel and compared to those in p+p collisions and in Pb+Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. Prospects for future Υ measurements with the STAR experiment are also discussed.

Keywords: Quark-Gluon Plasma (QGP), Color screening, Dissociation, Suppression, Upsilon, STAR

1. Introduction

Quark-Gluon Plasma (QGP), a new state of matter where quarks and gluons are de-confined, is believed to have existed up to a few milliseconds after the Big Bang. Quarkonia could dissociate in the QGP due to color screening of quark-antiquark potential by the surrounding partons in the medium [1], which was suggested as a signature of QGP formation in heavy-ion collisions. Moreover, different quarkonium states may dissociate at different temperatures depending on their binding energies [2, 3, 4]. This so-called "sequential melting" phenomenon could be used to deduce the temperature of the QGP. However, other effects, such as regeneration from deconfined heavy quark-antiquark pairs, shadowing and antishadowing of nuclear parton distribution functions and co-mover absorption, need to be taken into account when interpreting experimental results. Compared to charmonium production at RHIC energies, bottomonium production has several advantages: 1) the regeneration contribution is negligible due to the the much smaller $b\bar{b}$ production cross section ($\sigma_{b\bar{b}} \approx 1.87^{+0.99}_{-0.67}$ μb [5] compared to $\sigma_{c\bar{c}} \approx 550-1400$ μb [6]); 2) the cross section for inelastic collisions of Υ with hadrons is very small, hence the co-mover absorption is predicted to be minimal [7]; 3) the suppression of Υ production due to cold-nuclear-matter (CNM) effects has been measured to be smaller than that for J/ψ reported by NA50 [8]. Thus, the Υ family is expected to be a cleaner and more direct probe of the QGP, and the corresponding color deconfinement effects.

Υ production has been studied via the di-electron decay channel at STAR in different collision systems, including p+p, d+Au and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV [9]. The latest Υ measurement via the di-electron channel in U+U collisions at $\sqrt{s_{\rm NN}}$ = 193 GeV allows a study of Υ suppession in a new heavy-ion collision system [10]. Since 2014, a new detector, the Muon Telescope Detector (MTD), has been fully installed and taking data, allowing measurements of Υ production via the di-muon channel. Compared to the di-electron channel, the di-muon channel has better sensitivity to different Upsilon states due to the reduced bremsstrahlung radiation.

2. Υ $R_{\rm AA}$ via the di-electron channel in U+U and Au+Au collisions

$\Upsilon \to e^+e^-$ decays were reconstructed using the Time Projection Chamber (TPC) and Barrel ElectroMagnetic Calorimeter (BEMC) with full azimuthal coverage over

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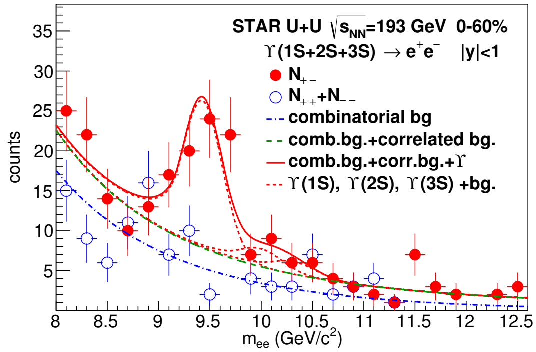

Figure 1: *(Color online)* Reconstructed invariant mass distribution of ϒ candidates [10], Fits to the combinatorial background, $b\bar{b}$ and Drell-Yan contributions and to the ϒ peaks are plotted as dash-dotted, dashed and solid lines respectively. The fitted contributions of the individual ϒ(1*S*), ϒ(2*S*) and ϒ(3*S*) states are shown as dotted lines.

the pseudorapidity range $|\eta| < 1$. Electron identification (eID) was achieved by measuring the ionization energy loss (dE/dx) and track momentum by the TPC, as well as the energy deposition in the BEMC. In addition, shower profiles measured by the Barrel Shower Maximum Detector (BSMD) were used in Au+Au collisions to further suppress hadron contamination. The identified electron and positron candidates are paired to reconstruct the invariant mass of the ϒ candidates.

The $\Upsilon(1S+2S+3S)$ and $\Upsilon(1S)$ R_{AA} in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV were calculated by dividing the invariant ϒ yields in U+U collisions by those in p+p collisions scaled by the number of binary nucleon-nucleon collsions ($N_{\rm coll}$) [10]. They are shown as a function of the number of participating nucleons ($N_{\rm part}$) in Fig. 2 and compared to those in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV within $|y| < 1$ from STAR [9] , within $|y| < 0.35$ from PHENIX [11], and in Pb+Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV within $|y| < 2.4$ from CMS [12]. $\Upsilon(1S+2S+3S)$ suppression becomes significant only in the most central collisions at RHIC energies. After combining U+U and Au+Au results, we find that $R_{\rm AA}^{\Upsilon(1S)} = 0.63 \pm 0.16 \pm 0.09$, which suggests that $\Upsilon(1S)$ is significantly but not completely suppressed in central heavy-ion collisions at top RHIC energies. While both the RHIC and LHC data show suppression in the most central bins, $R_{\rm AA}^{\Upsilon(1S)}$ is slightly, although not significantly, higher in semi-central collisions at RHIC than that at the LHC.

In Fig. 3, we compare STAR measurements to different theoretical models [13, 14, 15]. An important source of uncertainty in model calculations for quarkonium dissociation stems from the unknown nature of the

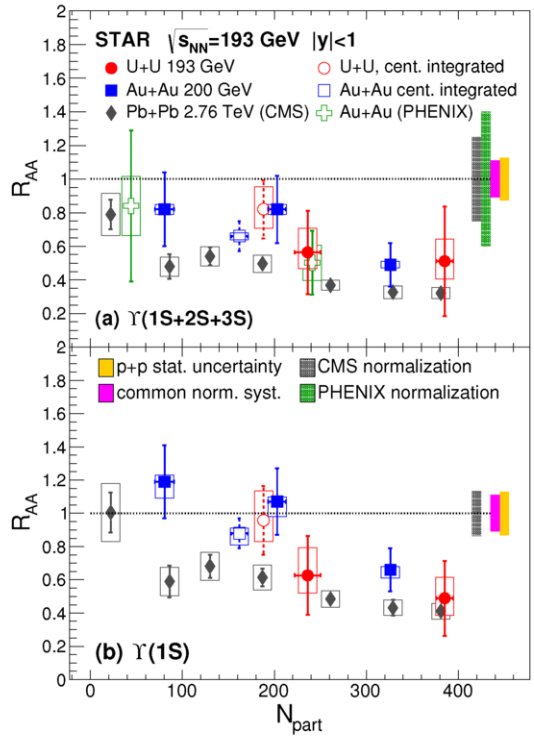

Figure 2: *(Color online)* $\Upsilon(1S+2S+3S)$ (a) and $\Upsilon(1S)$ (b) $R_{\rm AA}$ vs $N_{\rm part}$ in $\sqrt{s_{NN}}$ =193 GeV U+U collisions (solid circles) [10], compared to 200 GeV RHIC Au+Au (solid squares [9] and hollow crosses [11]), and 2.76 TeV LHC Pb+Pb data (solid diamonds [12]). Each point is plotted at the center of its bin. Centrality integrated (0-60%) U+U and Au+Au data are also shown as open circles and squares, respectively.

in-medium potential between the quark-antiquark pairs. Two limiting cases that are often used are the internal-energy-based heavy quark potential corresponding to a strongly bound scenario (SBS), and the free-energy-based potential corresponding to a more weakly bound scenario (WBS) [16]. The model of Emerick, Zhao and Rapp [13] includes CNM effects, dissociation of bottomonia in the hot medium (assuming a temperature of $T = 330$ MeV) and regeneration for both the SBS and WBS scenarios. The Strickland-Bazow model [14] calculates dissociation in the medium in both a free-energy-based "model A" and an internal-energy-based "model B", with an initial central temperature $428 < T < 442$ MeV. The model of Liu *et al.* [15] uses an internal-energy-based potential and an input temperature $T = 340$ MeV. In Fig. 3 we show all three internal-energy-based models together with the "model A" of Ref. [14] as an example for the free-energy-based models. The comparision between data and theoretical predictions suggests that internal-energy-based mod-