Abstract. Quarkonia production can be used to investigate the properties of the dense matter produced in heavy-ion collisions at RHIC because the production is theorized to be suppressed due to the Debye color screening of the potential between the heavy quarks. Lattice calculations indicate that a sequential suppression of quarkonia states in heavy-ion collisions will give us a model dependent measurement of the temperature of the Quark Gluon Plasma (QGP). Suppression is determined by calculating \( R_{\text{AA}} \), which is the ratio of the production in p+p scaled by the number of binary collisions to the production in Au+Au. The \( \Upsilon \) states are of particular interest because at 200 GeV the effects of recombination and co-mover absorption are smaller than for \( \psi/J_0 \), which lowers the systematic uncertainty of the interpretation of the \( R_{\text{AA}} \) calculation. It is also important to consider cold nuclear effects, which can be determined from d+Au collisions. We will present our results for mid-rapidity \( \Upsilon \) production in p+p, as well as our preliminary results in d+Au and Au+Au at \( \sqrt{s_{\text{NN}}} = 200 \text{ GeV} \). These results will then be compared with theoretical QCD calculations.

1. Introduction

Suppression of quarkonia due to the Debye screening of the potential between the two heavy quarks was thought to be a distinct signature of QGP formation [1]. \( J/\psi \) suppression was observed in heavy-ion collisions at both SPS and RHIC [2]. This indicates that the strongly interacting matter formed in heavy-ion collisions (sQGP) does modify the production of quarkonia. The magnitude of \( J/\psi \) suppression in both systems was similar despite the different energy densities, indicating that other physics processes besides Debye screening needed to be accounted for. These processes include statistical recombination of \( Q\bar{Q} \) pairs, co-mover absorption and feed-down from higher states. All of these processes have a smaller effect on the \( \Upsilon \) family than for the \( \psi \) family at 200 GeV. However, measuring the \( \Upsilon \) family is difficult because it has a very small cross-section which requires a large amount of integrated luminosity. An important measurement that can be made by studying the \( \Upsilon \) 1S, 2S, and 3S states is a model dependent determination of the sQGP temperature. This is determined by examining the ratio of the 2S and 3S states to the 1S state in heavy-ion collisions compared to the ratio in p+p collisions. At \( \sqrt{s_{\text{NN}}} = 200 \text{ GeV} \), lattice calculations indicate that the 3S should be completely dissociated, while the 2S state may dissociate and the 1S state should survive [3,4]. In order to measure the medium modification of the \( \Upsilon \)(1S, 2S, 3S) states at STAR, a baseline p+p measurement
was required. To understand whether medium modification in Au+Au collisions is due to the hot nuclear matter effects caused by the sQGP, cold nuclear matter effects need to be quantified. This is done by measuring the $\Upsilon(1S, 2S, 3S)$ yield in d+Au collisions.

2. STAR detectors and trigger

Upsilons are reconstructed at STAR through the decay channel $\Upsilon \rightarrow e^+e^-$. The Barrel Electromagnetic-Calorimeter (BEMC) [5] and the Time Projection Chamber (TPC) [6] are the two main detectors used in the STAR $\Upsilon$ analyses. The BEMC has a coverage of $|\eta| < 1$ and $0 < \phi < 2\pi$, and is used to measure the energy of the $\Upsilon$ daughters and for the trigger. The TPC has the same coverage as the BEMC and is used to determine the momentum and the ionization energy loss for particle identification. The two are used in conjunction to calculate $E/p$, which is also used for particle identification. In order to utilize the full luminosity seen at STAR an efficient two stage trigger was developed. The first stage is a hardware trigger (L0) which fires if a single tower in the BEMC is above the necessary threshold. The threshold for the p+p (d+Au, Au+Au) data presented in this paper is ~3.5 (4.3) GeV. This trigger can fire on every bunch crossing. The second stage is a topological software trigger which requires two three-tower BEMC clusters to be above two different thresholds. These clusters must also satisfy an invariant-mass and an opening-angle requirement [7,8,9].

3. Results

The baseline $p+p$ analysis presented in this paper is from $\int L \, dt = 8.8 \pm 0.8$ (syst.) pb$^{-1}$ taken during run 6 (2006). The electrons were selected using the ionization energy loss and the $E/p$ ratio as explained in section 2. The signal is a combination of the $\Upsilon(1S, 2S, 3S)$, Drell-Yan and $b\bar{b}$ yield. This is calculated by combining the unlike-charged electron pairs and subtracting the like-sign electron invariant-mass spectrum from it. The $\Upsilon(1S, 2S, 3S)$ is then determined by subtracting the Drell-Yan and $b\bar{b}$ yield from the signal as shown in figure 1.

![Figure 1.](image)

**Figure 1.** STAR measurement of the like-sign subtracted $e^+e^-$-invariant mass spectrum from $p+p$ collisions. The solid circles are from data with statistical error bars. The dot-dashed black line is the continuum contribution from Drell-Yan and
uncorrelated $b\bar{b}$ pairs. The solid red curve combines the dot-dashed black curve and the contribution from the three Crystal-Ball functions [11]. The red dotted histogram is the integral of the red curve [10].

The efficiency of the $\Upsilon$(1S, 2S, 3S) signal is determined by embedding a GEANT simulated $\Upsilon \rightarrow e^+e^-$ decay into a pythia event which is propagated through the detector geometry and then further embedded into a real zerobias event. A zerobias collision does not require any signals from any of the STAR detectors, only a bunch crossing coincidence. We find the cross section at mid-rapidity in p+p collisions to be:

$$\sum_{n=1}^{3} B(nS) \times \frac{d\sigma}{dy} \bigg|_{y=0} (nS) = 114 \pm 38\%_{24} \text{ pb} [10].$$

The $d+$Au analysis presented in this paper is from $\int L \ dt = 32 \ nb^{-1}$ of integrated luminosity from the run 8 (2008) d+Au data. The amount of inner material in the STAR detector was reduced compared to the p+p and Au+Au $\Upsilon$ analyses. This allows for better resolution. The yield of $\Upsilon$(1S, 2S, 3S), Drell-Yan and $b\bar{b}$ was determined by counting the number of like-sign subtracted invariant mass pairs from 7.5 to 11 GeV/c$^2$. This entire yield was used to calculate $R_{dA}$ which was found to be $R_{dA} = 0.78\pm0.28\pm0.20$. This is consistent with $N_{\text{binary}}$ scaling which means that cold nuclear matter contributions are small [9]. As shown in figure 2, this $d+$Au result is consistent with a Color Evaporation Model (CEM) calculated which includes anti-shadowing.

The Au+Au data presented here is from $\sim500 \ \mu b^{-1}$ of integrated luminosity taken during run 7 (2007). The total yield of $\Upsilon$(1S, 2S, 3S), Drell-Yan and $b\bar{b}$ was calculated in the same manner as the p+p and d+Au analysis. In the 0-60% centrality bin, this yield was 95 counts, with a 4.6$\sigma$ significance. The unlike-sign signal and like-sign background for this calculation are shown in figure 3. In the 0-10% centrality bin, the yield was 47 counts with a significance of 3.5$\sigma$. Determination of the corrected $\Upsilon$(1S, 2S, 3S) yield from this value is in process.
Figure 3. (Left) The STAR measurement of the invariant yield via the dielectron channel for Au+Au collisions in the 0-60% centrality region. The red histogram is the like-sign background yield and the blue circles are the unlike sign yield. The black curve is a power-law multiplied by an erf function used to determine the trigger effect on a continuum process and will be used to model the Drell-Yan and b\bar{b} background yields. (Right) The unlike minus the like sign distributions from the left graph.

4. Conclusions

The STAR experiment has measured the $\Upsilon(1S+2S+3S) \rightarrow e^+e^-$ cross section at midrapidity in p + p to be

$$\sum_{n=1}^{3} B(nS) \times \left| \frac{d\sigma}{dy} \right|_{y=0} (nS) = 114 \pm 38^{+23}_{-24} \text{ pb at } \sqrt{s_{NN}} = 200 \text{ GeV.}$$

The d+Au cross section for $\Upsilon(1S, 2S, 3S) + \text{Drell-Yan} + b\bar{b}$ was measured to be

$$\sum_{n=1}^{3} B(nS) \times \left| \frac{d\sigma}{dy} \right|_{y=0} (nS) = 35 \pm 4(\text{stat}) \pm 5(\text{syst}) \text{ nb.}$$

Combining these gives a $R_{dA} = 0.78\pm0.28\pm0.2$ which is consistent with CEM predictions including anti-shadowing. Preliminary uncorrected yields of $\Upsilon(1S, 2S, 3S) + \text{Drell-Yan} + b\bar{b}$ of 95 in the 0-60% centrality bin of Au+Au and 47 in the 0-10% bin was also presented.

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