HEAVY-QUARKONIA IN THE STAR EXPERIMENT

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Abstract.
Heavy Quarkonium states modifications in relativistic heavy ion collisions have been of great interest since the proposal by Matsui and Satz of $J/\psi$ suppression as a signature of Quark-Gluon Plasma (QGP) formation. Recent studies suggest that the excited states $\chi_c$, $\psi(2S)$ and $\Upsilon(3S)$ melt sequentially[1, 2] and the amount of observed suppression depends on the state and medium conditions. Therefore, this suppression pattern may be used as a probe of the medium temperature. In this work we present preliminary results on the charmonium and bottomonium measurements performed by the STAR experiment at RHIC for p+p and Cu+Cu collisions at $\sqrt{s_{NN}} = 200 GeV$

1. Introduction

The main idea of this work is to make a comparison between the $J/\psi$ and $\Upsilon$ (1s+2s+3s) production in p+p and Cu+Cu. These heavy quarkonia states are measured in STAR through the $e^+e^-$ decay channel. From lattice QCD calculations[1, 2] it is expected a suppression of these states in heavy ion collisions due to the sequential melting of their excited states

2. Experimental Setup

The experimental setup for this measurement relies in basically three subsystems of the STAR experiment[3, 4, 5] which are the Time Projection Chamber (TPC), Barrel Electromagnetic Calorimeter (BEMC) and Central Trigger Barrel (CTB), this last one only for triggering $J/\psi$ events in p+p. All of these subsystems have full azimuthal coverage. The TPC has $|\eta| < 1.8$ and provides up to 45 ionization points to charged tracks within its acceptance, allowing $dE/dx$ and momentum reconstruction. The BEMC is a lead-scintillator sampling electromagnetic calorimeter with equal volumes of lead and scintillator, divided in 4800 towers within the $|\eta| < 1$ range, each of them with a face area of $\Delta \phi, \Delta \eta = (0.05, 0.05)$. The detector resolution on deposited electromagnetic energy is $dE/E \sim 16% \sqrt{E}$. TPC was fully installed for both, p+p and Cu+Cu runs, while the BEMC was $\sim 3/4$ installed for Cu+Cu and fully installed for p+p. The CTB is a barrel made of scintillator slats that are sensitive to charged particles only. As the heavy quarkonia states have really low cross-sections and their decay channel observed in STAR has a also relatively low branching ratio,
the measurements have to improve its statistics relying in either, a large minimum bias data set (MBT), which was the case for Cu+Cu, or in special dedicated triggers as in p+p which are undetailed in the following section.

3. Trigger Setup

The STAR Quarkonia Trigger is a two level trigger system designed to optimize the STAR measurement capabilities of the di-electron decay channel for the heavy quarkonia states. The following sub-sections details the trigger for J/ψ, while the Υ trigger system is detailed in reference[6]. For the Cu+Cu run there were not specific quarkonia triggers, and the measurements rely on large MB (∼40M events for J/ψ) and a high tower trigger (HTT) (∼9M events for Υ) data sets. This HTT trigger have similar effect as the L0-Υ trigger[6]. The L0-J/ψ trigger is a topological trigger where the decision is made at the hardware level. It divides the BEMC into 6 sectors in φ and 2 in η, called patches. There are required at least 2 BEMC towers in non-adjacent patches, with energy above the threshold of 1.2 GeV (high-towers, or HT). With all these requirements fulfilled the L2-J/ψ is started. The L2 is a software level decision. It is basically the same algorithm described in [6], but with the extra requirement that the HT that seeds the L2 must match a CTB slat adc>3 in order to avoid photons. The remaining difference is the value of the invariant mass parameter, according to the specific quarkonium state.

4. Electron Identification

The electron identification[6] is a central issue in the STAR Quarkonium Program once its measurements come from the e+e− decay channel. The problem is to separate electrons from hadron contamination, dominated mainly by pions. The electron identification procedure for quarkonia analysis is basically to choose TPC tracks with momentum \( p > 1 \text{ GeV/c} \) and \( 3 < \frac{dE}{dx} < 4.6 \). After this first selection the track is extrapolated to its correspondent BEMC tower, its energy \( E_{\text{tow}} \) is obtained and the ratio \( \frac{p}{E_{\text{tow}}} \) is computed. Those with \( \frac{p}{E_{\text{tow}}} < 2 \) are selected as electrons(positrons).

5. Results

Once the electrons (positrons) are selected they are put together in pairs and have their invariant mass calculated by the expression

\[
M^2 = 2E_1E_2(1 - \cos \theta_{12})
\]

where \( p_i \) is the momentum of the \( i \)-th particle and \( \theta_{12} \) is the angle between them. To estimate the background a mass spectrum is built up from the geometric mean between the positively charged pairs with the negatively charged ones multiplied by 2. The net signals (unlike signed pairs – like signed) are presented in figure 1. From there it is possible to see the enhancement of the signals due to the trigger system by comparing the different significances for p+p and Cu+Cu. In the J/ψ case it increases from ∼2.5 in Cu+Cu to ∼5.0 in p+p, and for Υ from ∼2.6 in Cu+Cu to 3.0σ in p+p. The p+p Υ measurement cross section calculated is \( BR \times \frac{d\sigma}{dy} |_{y=0} = 91\pm 28(\text{stat.})\pm 22(\text{sys.}) \) pb (BR accounts for branching of 1S+2S+3S states). This result agrees very well with pQCD-CEM calculations[7,8] presented in figure 2. For the other quarkonium states further analysis are needed before we can quote their cross sections.
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Figure 1. Invariant mass signals for the different quarkonia states: First row shows data from p+p, J/ψ (left) and Υ and in bottom line same sequence for Cu+Cu data. Two important remarks on this plot: (a) J/ψ data in p+p follows more closely the simulated line shape, indicating that a Gaussian fit is a poor approximation and (b) the Υ signal in Cu+Cu is on the limit of statistical significance to extract a cross section.

Figure 2. Υ cross section in STAR compared with theoretical values (pQCD-CEM calculation[7, 8]) and world data.
6. Perspectives

The heavy-quarkonia program in STAR will strongly benefit from the future upgrades of RHIC and STAR. The major impact upgrades are the luminosity enhancement (~40×) on the RHIC side and, from the STAR side a barrel Time-of-Flight detector (improves low $p_T$ PID), a barrel muon detector providing $\mu^+\mu^-$ measurements and the DAQ1000 allowing zero dead time in special triggers for rare probes.

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