Measurement of Υ production in $p{+}p$ collisions at $\sqrt{s} = 500$ GeV in the STAR experiment

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Abstract.
Quarkonium suppression was proposed as a signature of the quark-gluon plasma (QGP) formation. Different members of the quarkonium family are expected to melt at different temperatures providing an estimate of the temperature reached in the QGP. The Υ states offer a clean probe of the QGP, thanks to small secondary production and cold nuclear matter effects. Previous measurements at RHIC focused on colliding system and centrality dependence of Υ nuclear modification factor R_{AA}. The Υ R_{AA} as a function of p_T will provide additional information about Υ interaction with the QGP, which requires a p_T spectrum in $p{+}p$ collisions as a baseline. Measurement of the Υ p_T spectrum in $p{+}p$ collisions at $\sqrt{s} = 500$ GeV may provide such a baseline with high precision. It can be rescaled based on $pQCD$ calculations and used as a baseline for $Au{+}Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV.

In this paper, the status of Υ measurements in $p{+}p$ collisions at $\sqrt{s} = 500$ GeV in the STAR experiment is presented. In addition, with the help of the newly installed Muon Telescope Detector (MTD) it will be possible to measure Υ 1S, 2S and 3S states separately.

1. Introduction

Suppression of J/ψ in $A{+}A$ collisions due to color screening was proposed as a signature of QGP formation [1]. This idea extends to other heavy quarkonia like Υ. Υ offers an advantage over J/ψ as a tool for QGP studies because it is less affected by the secondary production due to statistical recombination of heavy flavor quark-antiquark pairs in the QGP. In addition, cold nuclear matter effects (CNM) should be the same for all Υ states. The small differences in their masses makes the interpretation of CNM on Υ easier. The Υ studies in STAR in $p{+}p$ collisions at $\sqrt{s} = 500$ GeV offer an opportunity to obtain the high precision p_T spectrum. It may be rescaled and used as a baseline for $Au{+}Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV to allow a study of dynamical aspects of Υ suppression.

2. Dataset

This analysis used data from $p{+}p$ collisions at $\sqrt{s} = 500$ GeV collected by the STAR experiment in 2011. The data were collected using a $High\ Tower$ trigger, which selected events containing a high energy electron. This was done by implementing an online requirement ($L0$ trigger) of at least one tower in the Barrel Electromagnetic Calorimeter (BEMC) [2] with $E > 4.3$ GeV ($L0\ tower$) and a coincidence in Beam-Beam Counters (BBC). The tracks originating from

collisions were recorded by the Time Projection Chamber (TPC) [3]. After reconstruction the events with primary vertices within $|V_z| < 200\,cm$ of the center of the TPC were selected. The sample used in this analysis consists of 160 million events, which correspond to an integrated luminosity of $\mathcal{L} \approx 21.5\,pb^{-1}$.

3. Analysis

We reconstruct Υ in the e^+e^- channel ($BR = 2.38 \pm 0.11\%$) [4]. Electron candidates are selected using ionizing energy loss $\frac{dE}{dx}$ measured by the TPC. Figure 1 presents the distribution of $\frac{dE}{dx}$ and momentum p for all tracks. The $\frac{dE}{dx}$ is converted into a normalized $n\sigma_e$:

$$n\sigma_e = \log\left(\frac{\frac{dE}{dx}\big|_{Measured}}{\frac{dE}{dx}\big|_{Expected}}\right)/\sigma. \tag{1}$$

Here, σ is the $\frac{dE}{dx}$ resolution. Tracks with $-1.2 < n\sigma_e < 3$ are identified as electron candidates. Only tracks with $p > 1\,\text{GeV}/c$ are selected to reduce background.
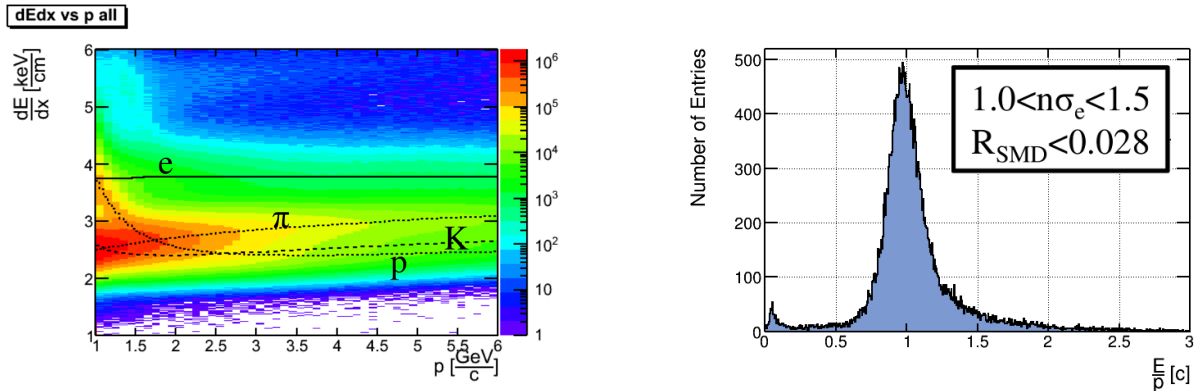

Figure 1. Energy loss $\frac{dE}{dx}$ as a function of momentum. The lines are theoretical values of $\frac{dE}{dx}$ from the Bichsel [5] functions for e, π, K and p.

Figure 2. Distribution of $\frac{E_{CLU}}{p}$ for tracks with $1.0 < n\sigma_e < 1.5$ and $6 < p < 8\,\text{GeV}/c$ matched to BEMC towers and within $R_{SMD} < 0.028$ of a reconstructed cluster.

Information from the BEMC is used to further increase the purity of the electron sample. Each track is matched to the BEMC tower and energy in that tower is extracted as E_{TOW}.

Since electromagnetic showers could deposit energy in more than one tower, we reconstruct 3-tower clusters to recover full electron energy (E_{CLU}). Clusters are made by combining the tower pointed by a track and 2 neighbouring towers with the highest and second highest energies. The distance between the energy-weighted center of a cluster and a track projected to the Shower Maximum Detector layer of BEMC ($R_{SMD} = \sqrt{\Delta\eta^2 + \Delta\phi^2}$) is calculated.

Having reconstructed clusters, electron candidates are required to have $R_{SMD} < 0.028$. Electrons are expected to leave all their kinetic energies in the BEMC ($\frac{E}{pc} \sim 1$), so a cut $0.55 < \frac{E_{CLU}}{pc} < 1.45$ is applied. The distribution of $\frac{E_{CLU}}{p}$ for pure electron candidates with tight $\frac{dE}{dx}$ cut at $6 < p < 8\,\text{GeV}/c$ is presented in Fig. 2. Since the size of BEMC towers are close to the Moliére radius [2], most of the energy is expected to be deposited in a single tower. Thus it is required that $\frac{E_{TOW}}{E_{CLU}} > 0.5$.

The selected tracks are combined into pairs for Υ reconstruction and invariant mass is calculated. At least one track in a pair has to be matched to a $L0\,tower$.

4. Signal

Υ signal is calculated by first obtaining the invariant mass distribution of e^+e^- pairs and a distribution of combinatorial background from both e^+e^+ and e^-e^- pairs. The e^+e^- distribution contains signal and both combinatorial and correlated background. The latter includes $b\bar{b}$ and Drell-Yan contributions. The background contributions are estimated by obtaining their functional parametrizations through fitting the combinatorial background in data or $b\bar{b}$ and Drell-Yan in Monte Carlo simulations. In addition, the shape for each of the Υ states is described by a Crystal Ball function [6], whose parameters are fixed based on MC simulation taking into account STAR detector responses. However, the relative contribution of each Crystal Ball function describing Υ 1S, 2S and 3S states is set free during fitting.
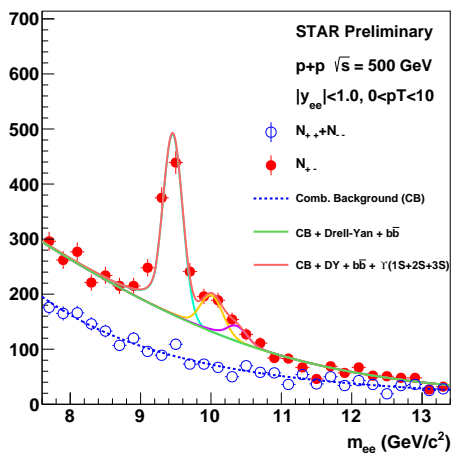

Figure 3. Invariant mass distribution of unlike-sign pairs (red closed circles) and like-sign pairs (blue open circles). The lines are various components of a simultaneous fit to both histograms. It includes combinatorial background (blue line), sum of: combinatorial+$b\bar{b}$+Drell-Yan (green line) and total Υ signal on top of background (red line). Also shown are the Crystal Ball functions for 1S (teal), 2S (orange) and 3S (violet) states.

Figure 4. Uncorrected Υ p_T spectrum of combined 1S+2S+3S states (red closed circles) and 1S state (black diamonds) only.

The fit is done simultaneously to like-sign and unlike-sign pairs using RooFit [7] and its result is shown in Fig. 3. Finally, the Υ (1S+2S+3S) yield is calculated by integrating e^+e^- distribution and subtracting the integral of all background functions in the $8.8 < m_{ee} < 11\,\mathrm{GeV}/c^2$ mass range. The data allows separation of 1S state from the 2S and 3S, so the Υ 1S yield is calculated in the same way in the range of $8.8 < m_{ee} < 9.8\,\mathrm{GeV}/c^2$.

The total raw yield is divided into 5 p_T bins from $0-10\,\mathrm{GeV}/c$, which is shown in Fig. 4. No efficiency corrections are included. Results are summarized in Table 1 as well.

5. Outlook

STAR has undergone a few upgrades recently. The Muon Telescope Detector (MTD) [8] and Heavy Flavor Tracker (HFT) are the new detectors in STAR added for the 2014 run.

The MTD will allow precise measurements of quarkonia in the dimuon channel. Muons exhibit less bremsstrahlung than electrons and there is no background from γ conversion. The
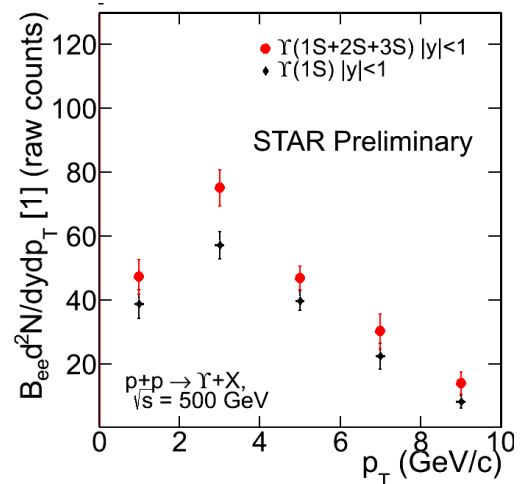
Table 1. Summary of obtained raw Υ yield. The 1S+2S+3S yield is calculated in $8.8 < m_{ee} < 11\,\text{GeV}/c^2$, while 1S in $8.8 < m_{ee} < 9.8\,\text{GeV}/c^2$.

p_T [GeV/c]	1S+2S+3S Yield		1S Yield	
0-2	189 ± 22	(12%)	155 ± 18	(12%)
2-4	301 ± 23	(8%)	229 ± 18	(8%)
4-6	188 ± 15	(8%)	159 ± 13	(9%)
6-8	121 ± 22	(19%)	90 ± 16	(18%)
8-10	56 ± 15	(27%)	32.9 ± 8.4	(26%)

MTD will allow R_{AA} measurements separately for each of the Υ states. The statistical precision for Υ R_{AA} as a function of N_{part} are shown in Fig. 5.
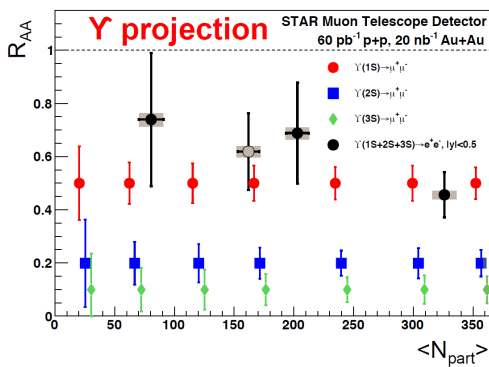

Figure 5. Expected precision for Υ R_{AA} as a function of N_{part} with MTD. The red circles are for 1S, the blue squares are for 2S and green diamonds are for 3S states. For comparison, recent STAR results are also shown as black closed and open circles [9].

The HFT is a silicon vertex detector, which will provide precision tracking for STAR. It will allow direct reconstruction of open charm and beauty decays. For Υ studies, the direct $b\bar{b}$ cross section measurement with the HFT will help understand the background.

6. Summary

The experimental method in STAR for Υ measurements in $p+p$ at $\sqrt{s} = 500$ GeV was presented. The uncorrected yield of Υ 1S in $8.8 < m_{ee} < 9.8\,\text{GeV}/c^2$ and combined $\Upsilon(1S+2S+3S)$ states in $8.8 < m_{ee} < 11\,\text{GeV}/c^2$ were obtained. The results are summarized in Table 1. Based on that, the precision of the invariant yield is expected to be better than 20% for $p_T < 8\,\text{GeV}/c$ and even better than 10% for $2 < p_T < 6\,\text{GeV}/c$. In addition prospects for Υ measurements in STAR were also reported.

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