Measurements of Non-photonic Electron Production and Azimuthal Anisotropy in $\sqrt{s_{NN}}$ = 39, 62.4 and 200 GeV Au+Au Collisions from STAR at RHIC

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Abstract

During the RHIC 2010 run, STAR has collected a large amount of minimum-bias, central and high p_T trigger data in Au+Au collisions at $\sqrt{s_{NN}}$ = 39, 62.4 and 200 GeV with the detector configured to minimize photon conversion background. In this article we report on a new high precision measurement of non-photonic electron mid-rapidity invariant yield, improved nuclear modification factor and v_2 in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. We also present measurements of mid-rapidity invariant yield at $\sqrt{s_{NN}}$ = 62.4 and v_2 at $\sqrt{s_{NN}}$ = 39 and 62.4 GeV.

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1. Introduction

Exploiting the merits of heavy quarks is one of the most important and promising tools to probe the strongly interacting partonic medium created in heavy-ion collisions. Heavy quarks are mostly created through gluon fusion [1], almost exclusively [2] early in the heavy-ion collision, therefore, they experience all stages of the medium evolution. Also, their masses are external to QCD [3] and thus are not modified by the presence of the medium. Hence, the kinematics of emerging heavy quarks carry a memory of their interactions with the medium. By comparing the heavy quark production in heavy-ion collisions to the baseline production in $p + p$ and d+Au collisions, we seek to further understand the flavor dependence of energy loss in the medium. Azimuthal anistropy of heavy quarks provides further information on the strength of their interaction with the medium, and better discrimination between theoretical models.

In this article we report on the preliminary results of measuring the production of electrons from heavy flavor semi-leptonic decays, so-called non-photonic electrons (NPE). We show a new high precision measurement of NPE production at mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, then using our previously published $p + p$ measurement [4] we show an improved nuclear modification factor R_{AA} and compare it to theoretical models. Then we show measurements of NPE azimuthal anistropy, $v_2\{2\}$, $v_2\{4\}$ and $v_2\{EP\}$. Finally, we show measurements of NPE production in Au+Au collisions at $\sqrt{s_{NN}}$ = 62.4 GeV, and $v_2\{2\}$ measurements at $\sqrt{s_{NN}}$ = 39 and 62.4 GeV.

[1] A list of members of the STAR Collaboration and acknowledgements can be found at the end of this issue.

2. Datasets and Analyses

In RHIC run 2010, STAR has sampled nearly 2.6 nb^{-1} luminosity of Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Minimum Bias (MB) trigger data is used for low p_T electrons, while high p_T trigger (HT) data provides higher statistical precision for p_T > 2 GeV/c. We have also utilized data from an independent 0−5% centrality trigger. We use about 1 nb^{-1} for the $\sqrt{s_{NN}}$ = 200 GeV results we show here. During the same RHIC run STAR has also collected Au+Au collision data at $\sqrt{s_{NN}}$ = 39 and 62.4 GeV, which allows us to search for the onset of heavy quark suppression and flow.

For analyses in all collision energies, the most important detector is the STAR Time Projection Chamber (TPC) with large acceptance, which provides tracking and dE/dx for electrons identification. Hadron rejection is done utilizing Time of Flight (TOF) [6] information at low p_T and the Barrel Electromagnetic Calorimeter (BEMC) [7] at high p_T. The BEMC is also used for triggering on high p_T electrons.

To extract NPE, we statistically subtract the contribution of photonic electrons (PE) from the identified inclusive electrons. By reconstructing the invariant mass of electron pairs we estimate the PE contribution from gamma conversion, and π^0, η Dalitz decays. Extracted yield of PE is then corrected by a p_T dependent reconstruction efficiency determined from simulation to be at the level of 30-60%. Other non-photonic background sources are electrons from vector mesons di-electron decays (p_T < 3 GeV/c), and electrons from heavy quarkonia and Drell-Yan decays (p_T > 2.0 GeV/c). Contribution from J/ψ can be non-negligible in this region, estimates based on measured J/ψ experimental measurements show it can be as large as 20% of the measured non-photonic electrons. This contribution has been subtracted from $\sqrt{s_{NN}}$ = 200 GeV invariant yields we report in this article.

3. Results

Figure 1 left shows the new measurement of NPE mid-rapidity differential invariant yield for p_T = 1.5 - 10 GeV/c. The novelty of this measurement lies in the achieved high statistical precision. The large amount of statistics allows differentiating the measurements in five centrality bins, in addition to a 0−5% centrality bin from a central trigger. With such a precision and guided by the scaled FONLL upper bound, one can qualitatively notice the suppression of the yield in Au+Au collisions compared to $p + p$ collisions despite the large log-scale spanned in the figure.

Figure 1 upper-right panel shows NPE R_{AA} using 0 − 10% centrality spectra and STAR published $p + p$ [4] results compared to a collection of models of different energy loss mechanisms. As we see in the Figure, despite the success of describing the suppression of light hadrons [9], gluon radiation alone fails to explain the observed large NPE suppression at high p_T. The large uncertainty from our baseline p+p measurement dominates the current overall uncertainty. Analysis of the large amount of collected high quality data from RHIC runs 2009 and 2012 are needed to improve the baseline precision. However, to exploit the high precision of this measurement, it will be interesting to see theoretical predictions for the quenched invariant yields rather than the R_{AA} only. With the current precision the predictions from all other energy energy loss models describe the data.

Figure 1 lower-right shows NPE v_2 measurements from 2- and 4- particle correlations and event plane method, represented as $v_2\{2\}$, $v_2\{4\}$ and $v_2\{EP\}$ in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The $v_2\{2\}$ and $v_2\{EP\}$ are consistent with each other for p_T > 3 GeV/c. While both show a pronounced systematic increase in v_2 towards high p_T, at this point we cannot distinguish

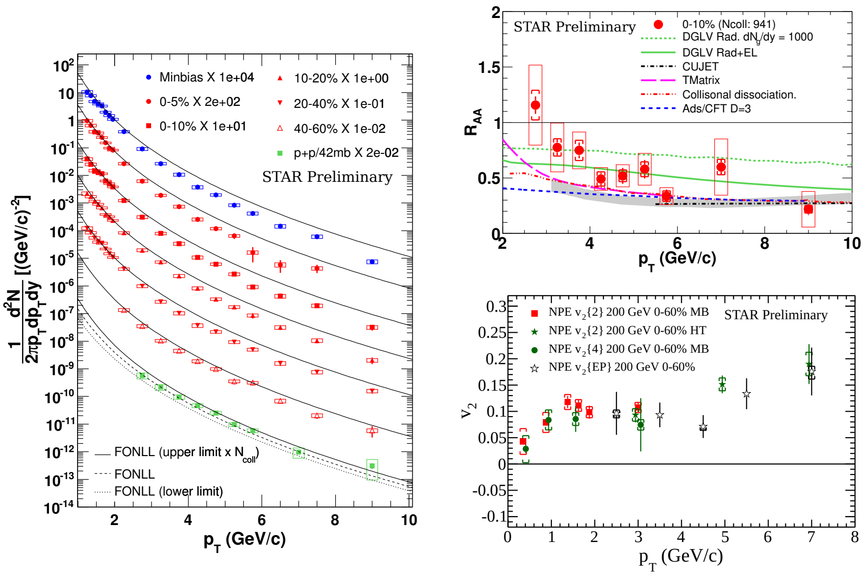

Figure 1: (Color online) (Left) Invariant yields vs. p_T of non-photonic electron at $\sqrt{s_{NN}}$ = 200 GeV, and scaled STAR published $p+p$ [4]. Error bars and boxes are statistical and systematic errors, respectively. FONLL predictions are scaled by N_{coll} shown as curves. (Upper-right) Non-photonic electrons nuclear modification factor, R_{AA}, at $\sqrt{s_{NN}}$ = 200 GeV compared to models [9]-[13]. Grey band is the light hadrons R_{AA}. Error bars and brackets are Au+Au statistical and systematic errors, respectively. Error boxes are the uncertainties from our baseline $p + p$ measurement. (Lower-right) Non-photonic electrons azimuthal anistropy $v_2\{2\}$, $v_2\{4\}$ and $v\{EP\}$ at $\sqrt{s_{NN}}$ = 200 GeV. Error bars and brackets are statistical and systematic errors, respectively.

whether this rise is due to jet-like correlations unrelated to the reaction plane or due to the path length dependence of partonic energy loss. For $p_T < 3$ GeV/c we show both $v_2\{2\}$ and $v_2\{4\}$. In $v_2\{4\}$ the non-flow contribution is negligible and the flow fluctuations contribution is negative, hence providing a lower bound on the v_2 of NPE. Both v_2 measurements are finite, which indicates a strong charm-medium interaction at $\sqrt{s_{NN}}$ = 200 GeV.

To provide more experimental discrimination power for theoretical models STAR is extending its NPE program to lower energies. The quest is to see if the energy loss of heavy quarks is lessened or turned off at lower energies. Figure 2 shows NPE invariant yield in Au+Au collisions at $\sqrt{s_{NN}}$ = 62.4 GeV together with a scaled FONLL prediction. While a previous $p+p$ measurement at the ISR [8] seems to agree with FONLL upper-band, our measurement is systematically higher than both. Measurement of $v_2\{2\}$ at lower energies shown in Figure 3 seem to be consistent within errors with that at $\sqrt{s_{NN}}$ = 200 GeV for $p_T > 1.0$ GeV/c. The results for data points at $p_T < 1.0$ GeV/c seem to hint at a milder charm-medium interaction compared to those at $\sqrt{s_{NN}}$ = 200 GeV.

4. Summary

In this article we reported on STAR new preliminary results of non-photonic electron measurements. The new NPE measurements in $\sqrt{s_{NN}}$ = 200 GeV collisions are precise in a broad

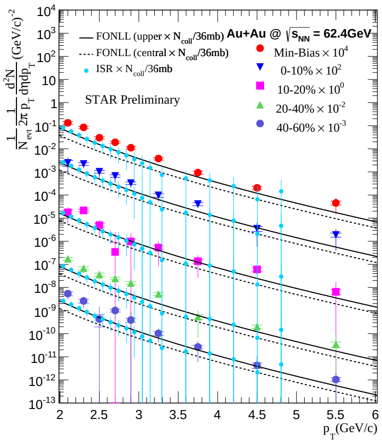

Figure 2: (Color online) Invariant yields vs. p_T of non-photonic electrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 62.4 GeV. Error bars and brackets are statistical and systematic errors, respectively. ISR $p + p$ collisions at $\sqrt{s_{NN}}$ = 62.2 GeV scaled by N_{coll} is also plotted [8]. FONLL predictions are scaled by N_{coll} shown as curves.

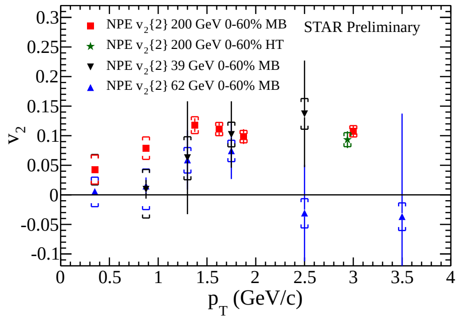

Figure 3: (Color online) Non-photonic electrons at $\sqrt{s_{NN}}$ = 39, 62.4 GeV azimuthal anistropy $v_2\{2\}$. Error bars and boxes are statistical and systematic errors, respectively.

p_T region. NPE nuclear modification factor measurement show a large suppression of NPE production in central Au+Au collisions. We observe large NPE v_2 at low p_T which indicate a strong charm-medium interaction. The v_2 increases towards higher p_T (> 3 GeV/c) is possibly due to jet-correlations unrelated to the reaction plane and/or due to path-length dependence of heavy quark energy loss.

At lower energies we reported on measurement of NPE invariant yield in Au+Au collisions at $\sqrt{s_{NN}}$ = 62.4 GeV which is systematically higher than a FONLL prediction. We have also presented our results of azimuthal anistropy at $\sqrt{s_{NN}}$ = 39 and 62.4 GeV by measuring $v_2\{2\}$ which for p_T < 1.0 GeV/c seem to hint at a milder charm-medium interaction than at $\sqrt{s_{NN}}$ = 200 GeV.

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