Measurements of charm hadron production and anisotropic flow in Au+Au collisions at 200 GeV with the STAR experiment at RHIC

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Abstract. Heavy flavor quarks, owing to their large masses, are predominantly produced through initial hard parton scatterings in heavy-ion collisions, and thus are excellent probes to study properties of the strongly coupled Quark Gluon Plasma (sQGP) medium produced in these collisions. Measurements of anisotropic flow harmonics of heavy flavor hadrons can provide information on the properties of the medium, including the heavy flavor transport coefficient. Charm quark hadronization mechanism in the sQGP medium can be studied through measurements of yields of different charm hadrons. In these proceedings we report on the measurements of elliptic and triangular flow harmonics of D^0 mesons as well as the yield ratios of $D_s^\pm/D^0$ and $\Lambda_c^\pm/D^0$, in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at RHIC with the STAR detector. These measurements use the STAR Heavy Flavor Tracker (HFT) to reconstruct charm hadrons via their hadronic decay channels. Results are compared to model calculations and the implications on the understanding of charm quark dynamics in the medium are discussed.

1 Introduction

Relativistic heavy-ion collisions at the RHIC and LHC create a hot dense medium of deconfined quarks and gluons. Experimental evidences, particularly the strong collective anisotropic flow of light flavor hadrons [1], suggest that the medium produced is strongly interacting and is in a local thermal equilibrium. It is therefore referred to as the strongly coupled Quark Gluon Plasma (sQGP) [2, 3]. In heavy-ion collisions, heavy flavor quarks (charm and bottom) are predominantly produced through initial hard parton scatterings and therefore are valuable probes to study the properties of the sQGP. In particular, measurements of the anisotropic flow (quantified using the coefficients v_n in the Fourier decomposition of the azimuthal distribution of particles [4]) of heavy flavor hadrons can help understand the interaction of heavy flavor quarks with the medium and constrain the values of the spatial diffusion coefficient D_s for the heavy flavor quarks in sQGP [5]. In these proceedings we present measurements of the elliptic (v_2) and triangular (v_3) flow of D^0 mesons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at RHIC with the STAR detector.

We also present measurements of the yield ratios of $D_s^\pm/D^0$ and $\Lambda_c^\pm/D^0$ in $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions at RHIC. These measurements can help understand the hadronization mechanism of charm quarks in the sQGP medium. Enhancements of these ratios, relative to the values in p+p collisions, are expected in the intermediate p_T region (3 - 6 GeV/c) if charm quarks hadronize via

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the coalescence mechanism in sQGP [6–9]. The magnitude of this enhancement is also sensitive to strangeness enhancement in sQGP for $D_s^{\pm}/D^0$ [6] and the presence of diquarks in the medium for $\Lambda_c^{\pm}/D^0$ [9].

2 Experiment and Analysis

The STAR detector at RHIC has a full azimuthal acceptance and a pseudorapidity (η) coverage of $|\eta| < 1$ [10]. The Heavy Flavor Tracker (HFT) [11] is a high-resolution silicon detector installed close to the beam pipe and provides excellent track pointing resolution, e.g. the track pointing resolution for kaons with $p_T = 1$ GeV/c is less than 40 μm. This allows to place cuts on the quantities describing the decay topology of heavy flavor hadrons, which can greatly enhance the signal significance. Particle identification (PID) at STAR is provided by the ionization energy loss (dE/dx) measured in the Time Projection Chamber (TPC) and the velocity measured using the Time of Flight (TOF) detector [10]. Results presented in these proceedings use about 900 M minimum-bias Au+Au events from the 2014 run at RHIC.

The $D^0(\overline{D^0})$ candidates are reconstructed through the $K^-\pi^+(K^+\pi^-)$ decay channel. Anisotropic flow measurements are made for D^0 (results presented in these proceedings are for D^0 and $\overline{D^0}$ hadrons combined) using the event plane method [4]. The D^0 candidates are correlated with the event plane constructed using TPC tracks in the opposite η hemisphere of the D^0 candidate and outside an additional η-gap of $|\Delta\eta| > 0.05$, to reduce non-flow contributions. More details on the measurement of elliptic flow of D^0 can be found in [12]. Reconstruction of the $D_s^{\pm}$ is done using the $D_s^{\pm} \rightarrow \pi^{\pm}\phi(1020) \rightarrow \pi^{\pm}K^{\pm}K^{\mp}$ decay channel and $\Lambda_c^{\pm}$ in the $\Lambda_c^{\pm} \rightarrow p^{\pm}K^{\mp}\pi^{\pm}$ channel. The TPC track reconstruction efficiency, acceptance corrections and PID efficiency are evaluated using embedding and data-driven methods [13], while the HFT track matching and topological cut efficiencies are evaluated through a fast simulation which takes the HFT to TPC track matching ratios and track pointing resolutions from data.

3 Results

Figure 1 shows the v_2 of D^0 mesons as a function of the D^0 p_T in the 0-80% centrality interval. It can be seen that the D^0 mesons have significantly non-zero values of v_2 for $p_T > 1.5$ GeV/c. The measured values are compared to the calculations from different models. The hydrodynamic model [14] tuned to reproduce the light flavor hadron v_2 is able to describe the D_0 v_2 for $p_T < 4$ GeV/c, suggesting that charm quarks may have achieved thermal equilibrium in these collisions. The TAMU model with no charm quark diffusion and the DUKE model with a fixed value for the charm diffusion coefficient, $2\pi T D_s = 7$ are inconsistent with the data, while transport models with a temperature-dependent diffusion coefficient in the range of $2 < 2\pi T D_s < 12$ are able to describe the measured D_0 v_2 [12]. The left panel of figure 2 shows the v_2 values divided by the number of constituent quarks (n_q) for D^0 mesons and a number of light flavor hadrons, as a function of $(m_T - m_0)/n_q$, where $m_T = \sqrt{m_0^2 + p_T^2}$ is the transverse mass and m_0 is the rest mass. The n_q-scaled v_2 values for all the species, including D^0, fall on the same curve and hence suggest that charm quarks have gained significant flow from their interactions with the sQGP medium. The right panel of figure 2 shows a similar plot for v_3. The scaled v_3 values for D^0 also agree with those of light flavor hadrons, albeit with larger statistical uncertainties.

The left panel of figure 3 shows the D_s/D^0 yield ratio (D_s here denotes both D_s^+ and D_s^-), as a function of p_T for the 0-10% and 10-40% centrality bins. The D_s/D^0 ratios are significantly enhanced in Au+Au collisions compared to PYTHIA [15] predictions for p+p collisions and to the world-data average of the fragmentation ratio from the measurements in p+p, e+e, and e+p collisions. The model

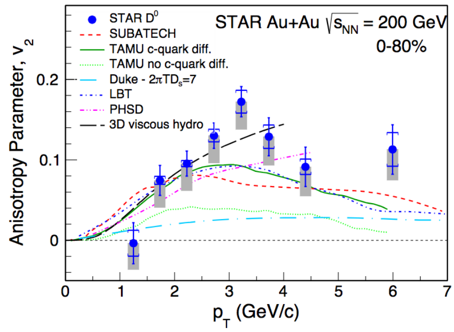

Figure 1. v_2 as a function of p_{T} for D^0 mesons in 0-80% centrality bin. The vertical bars and brackets represent statistical and systematic uncertainties, respectively. The grey band represents the estimated non-flow contribution [12].

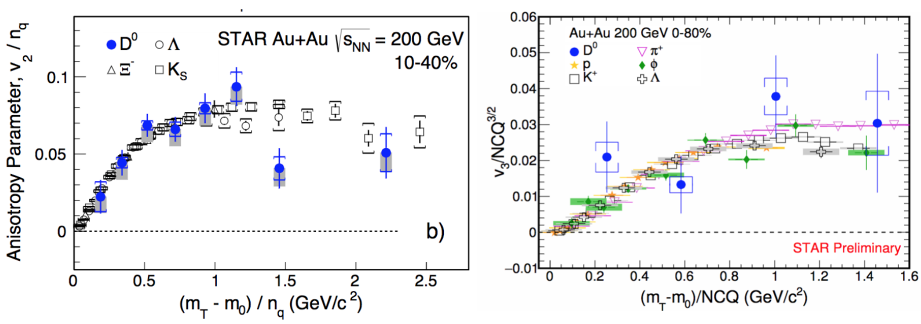

Figure 2. v_2/n_q in 10-40% centrality [12] bin (left) and $v_3/(n_q)^{3/2}$ in 0-80% centrality bin (right), as a function of $(m_T - m_0)/n_q$ for D^0 (solid circles) and light flavor hadrons.

prediction from the TAMU group [6], which includes coalescence of charm quarks, underpredicts the data, while the SHM calculation [16] is comparable to data in the low p_{T} region. The right panel of figure 3 shows the Λ_c/D^0 (Λ_c here denotes both Λ_c^+ and Λ_c^-) ratio measured in $3 < p_{\mathrm{T}} < 6$ GeV/c. The data shows a significant enhancement of the ratio compared to the PYTHIA prediction for p+p collisions. The SHM model [16] also underpredicts the data. The Ko model (0-5%) [9] calculations include coalescence of thermalized charm quarks and are closer to the measured values. However, both calculations, with and without di-quarks in the sQGP medium, are consistent with the data in the measured p_{T} region. The Greco model [8] also includes coalescence of charm quarks, but the values shown are for the Λ_c yield over the total D meson yield.

4 Summary and Outlook

Measurements of the elliptic and triangular flow harmonics for D^0 mesons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC are presented. The number-of-constituent-quark scaled v_2 for D^0 mesons agrees with those for light flavor hadrons suggesting that charm quarks acquire significant flow from their interactions with the medium. Hydrodynamic calculation can describe the data for $p_{\mathrm{T}} < 4$

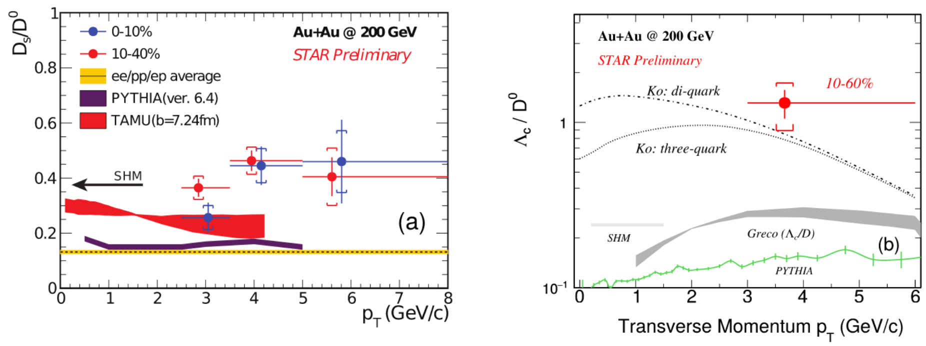

Figure 3. Yield ratios of D_s/D^0 in 0-10% and 10-40% Au+Au collisions (left) and of Λ_c/D^0 in 10-60% central Au+Au collisions (right) as a function of p_T. Vertical bars and brackets represent statistical and systematic uncertainties respectively

GeV/c, suggesting that charm quarks achieve as strong collectivity as light quarks in these collisions. Transport model calculations with a temperature-dependent charm diffusion coefficient in the range of $2 < 2\pi T D_s < 12$ for $T_c < T < 2T_c$ can also describe the data. The measurements of the D_s/D^0 and Λ_c/D^0 yield ratios in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are also presented. Both ratios show significant enhancements compared to the values in p+p collisions predicted by PYTHIA. For the D_s/D^0 ratio, the TAMU model calculation with coalescence of charm quarks underpredicts the measured values, while for the Λ_c/D^0 ratio, model calculations with coalescence of thermalized charm quarks in the sQGP medium are comparable with the data. STAR has collected two times more data in 2016 than in 2014, which will allow for measurements with better precision, particularly for the triangular flow and Λ_c/D^0 ratio, and extend the kinematic reach of the measurements.

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