Measurements of the nuclear modification factor and elliptic flow of ϕ mesons at RHIC

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The observation of meson and baryon grouping in the R_{CP} and v_2 measurements at intermediate p_T has been interpreted as a manifestation of bulk partonic matter hadronization through multi-parton dynamics such as recombination of partons. ϕ mesons provide unique sensitivity to test these theoretical scenarios, since the ϕ has a mass heavier than the proton and close to the hyperons. The R_{CP} and v_2 measurements of ϕ mesons from Run IV Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at STAR are presented. Energy and colliding system dependence of the ϕ yields at mid-rapidity are discussed. The results are compared to the measurements of other hadrons. Properties of strange quarks in the bulk matter at hadron formation are discussed.

1. INTRODUCTION

Strange particle production may be sensitive to the existence and properties of a deconfined partonic state formed in relativistic heavy-ion collisions. Current measurements of identified hadrons by STAR (K^0_s and Λ) [1] and PHENIX (proton and π^0) [2] show that the nuclear modification factor (R_{CP}) for the Λ differs from that of the K^0_s and R_{CP} for the proton differs from that of the π^0, which indicates a dependence on particle species of particle production. This phenomenon can be explained by quark coalescence or recombination models [3–5], in which the hadrons at intermediate p_T are predominantly formed by the coalescence of constituent quarks from a thermalized partonic system. The ϕ meson is of particular interest in distinguishing between dependence on mass or particle species, since the ϕ meson has a mass similar to that of the Λ baryon. Since the ϕ interaction cross-section with other hadrons is small [6], ϕ will retain information from the early hot and dense phase. Additionally, since kaon coalescence has been ruled out as the dominant ϕ production mechanism at RHIC [7], measurements of elliptic flow (v_2) of ϕ should be a sensitive probe for the build-up of pressure in the early reaction stage of relativistic heavy ion collisions.

2. TRANSVERSE MASS DISTRIBUTION

Reconstruction of ϕ mesons is accomplished by calculating the invariant mass (m_{inv}) of all possible pairs of K^+ and K^- candidates in each event for each transverse momentum (p_T) bin and centrality bin. The combinatorial background is calculated by using the

*For the full list of STAR authors and acknowledgments, see appendix 'Collaborations' of this volume.

mixed-event technique [7–9]. The transverse mass distributions of ϕ mesons from Au+Au collisions (at 62.4GeV, 130GeV [10] and 200 GeV, Run II and Run IV datasets), d+Au [11] and p+p [7] collisions (at 200 GeV) are measured at STAR. The collisions are divided into different centrality classes, where each centrality bin corresponds to a certain fraction of the total hadronic cross-section. The measured STAR ϕ meson spectra for $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions are consistent across the Run II and Run IV datasets.

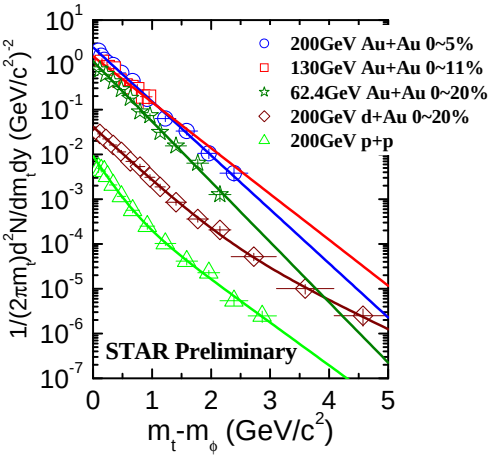

Figure 1. The transverse mass distributions of ϕ mesons for the most central collisions for different collision systems. Error bars are statistical errors only.

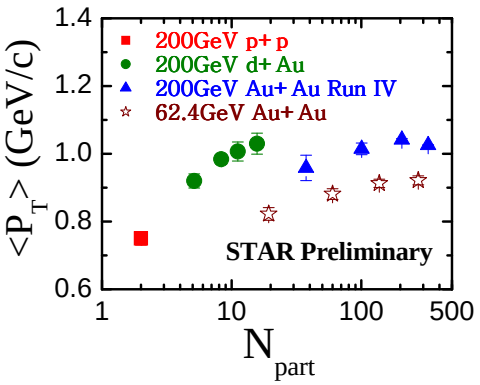

Figure 2. $\phi < p_T >$ as a function of participant number. Error bars are statistical errors only.

In order to compare the spectral shapes, the most central ϕ spectra for different collision systems are plotted together in Figure 1. It can be seen that the ϕ meson spectra for Au+Au collisions in the measured p_T range can be described by an exponential function for all collision energies. The ϕ spectra for d+Au and p+p collisions deviate from the exponential distribution and have a power-law tail in the intermediate p_T range, where the double-exponential function [11] can reproduce the experimental data well. Due to the limited p_T range for Au+Au collisions, measurements at $(m_t - m_\phi)$ >2.5 GeV/c^2 may be necessary to see if a power-law tail exists.

The system-size and beam-energy dependence of $\phi < p_T >$ is shown in Figure 2. For different collision systems at 200 GeV, the $< p_T >$ increases from p+p to d+Au collisions as a function of participant number (N_{part}). $\phi < p_T >$ in Au+Au collisions doesn't change significantly within error bars, unlike the general increasing trend for $\bar{p}, K^-$ and π^- [12,7]. This is consistent with an early freeze-out scenario for the ϕ-meson. If the ϕ hadronic scattering cross-section is much smaller than that of other particles, one would not expect the $< p_T >$ distribution to be appreciably affected by any final state hadronic rescatterings. It is also seen that the $< p_T >$ of the ϕ meson in Au+Au collisions at 62.4GeV is lower than that at 200 GeV. Since the $< p_T >$ carries information about radial flow, it may be different at different collision energies.

3. NUCLEAR MODIFICATION FACTOR (R_{CP})

R_{CP} is calculated as the ratio of the yields from central collisions to peripheral collisions scaled by the mean number of binary collisions. Comparisons of the R_{CP} for Au+Au

collisions (K^0_s, ϕ and Λ) and d+Au collisions (K^0_s, ϕ, Λ and Ξ) at 200 GeV are shown in Figure 3 and Figure 4, respectively. Only statistical errors are included in the figures.

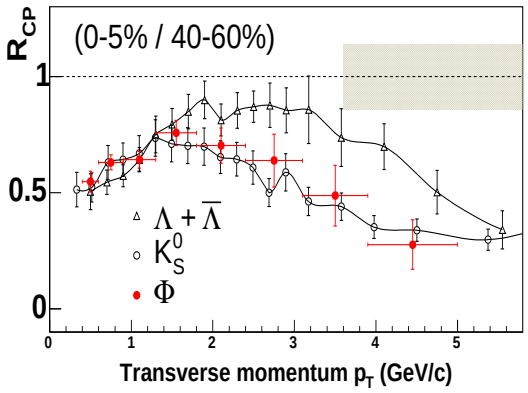

Figure 3. The ratio of yields in central collisions over peripheral collisions (R_{CP}) normalized by $\langle N_{bin} \rangle$ in Au+Au collisions at 200 GeV.

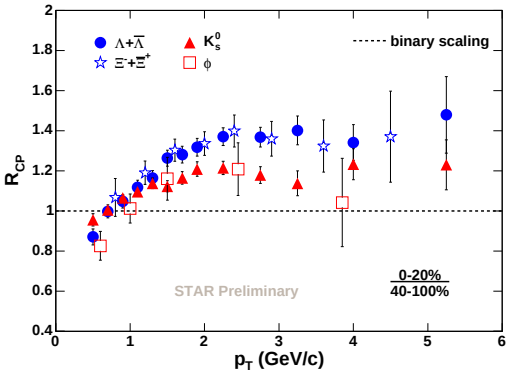

Figure 4. The ratio of yields in central collisions over peripheral collisions (R_{CP}) normalized by $\langle N_{bin} \rangle$ in d+Au collisions at 200 GeV.

In both collision systems at intermediate p_T, the R_{CP} of baryons (Λ and Ξ) is larger than that of mesons (K^0_s and ϕ), which implies that particle production in this p_T region is driven by the particles' types, not their masses. The R_{CP} results are consistent with the partonic recombination model predictions [3–5] that the centrality dependence of the yield at intermediate p_T depends more strongly on the number of constituent quarks than on the particle mass. There also may be a tendency for values of R_{CP} for all particles to approach each other at high p_T. For 200 GeV d+Au collisions, the measurements are consistent with the proposal by Hwa and Yang [13] that the particle type dependence of the Cronin effect may not be due to the initial parton scatterings alone. More data are needed for a firm conclusion.

4. ELLIPTIC FLOW OF ϕ MESONS IN 200 GeV Au+Au COLLISIONS

The first measurements of v_2 for ϕ at mid-rapidity in Run IV 200 GeV Au+Au collisions are presented in Figure 5. The v_2 is calculated as $\langle cos[2(\phi_i - \Psi^i_{RP})] \rangle$ and the auto-correlation is subtracted [14]. It can be seen that the v_2 of ϕ increases monotonically for $p_T < 2.0 GeV/c$ and becomes flat in the intermediate p_T range. Within statistical uncertainties, the minimum-bias ϕ meson results are similar to the v_2 of the K^0_s, which shows number of constituent quarks scaling [14,15]. However, the error bars in the intermediate p_T range are still large.

5. CONCLUSION

In summary, the measurements of ϕ transverse mass distributions at mid-rapidity from different collision systems at RHIC are reported. It is found that the shape of the ϕ spectra for Au+Au collisions in a limited p_T range can be described by an exponential function, while the ϕ spectra of d+Au and p+p collisions have a power-law tail in the intermediate p_T range and the double exponential function fits the data well. The R_{CP} for ϕ mesons

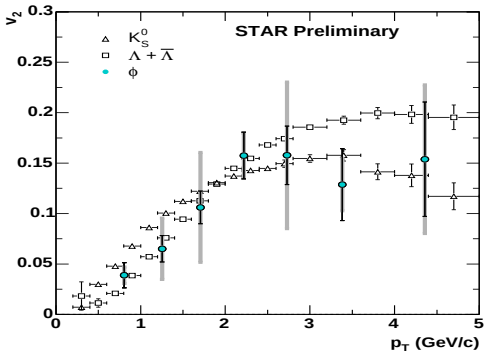

Figure 5. The v_2 parameter for ϕ meson as a funtion of p_T. In comparison, the v_2 for K^0_s and Λ has also been plotted. Systematic uncertainties from comparison of two methods are shown as gray bands.

in 200 GeV d+Au collisions shows the Cronin effect as seen in low energy p+A collisions [16]. The R_{CP} measurements are divided into two groups in both 200 GeV d+Au and 200 GeV Au+Au collisions in the intermediate p_T range, where the R_{CP} of baryons (Λ and Ξ) is larger than that of mesons (K^0_s and ϕ). This particle species dependence of R_{CP} will constitute a unique means to investigate the hadronization mechanism of the dense matter formed in nucleus-nucleus collisions. The measurements of v_2 for ϕ mesons in Run IV 200 GeV Au+Au collisions at STAR are also presented. It is seen that the v_2 of ϕ meson is similar to that of K^0_s. Since the ϕ meson is not produced via K^+K^- fusion [7], this implies partonic collectivity at RHIC.

Acknowledgments— Besides the acknowledgments in appendix, we wish to thank NSFC 10475108 and 03 QA 14066 for contributing to the travel expenses.

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