Nuclear modification and elliptic flow measurements for ϕ mesons at $\sqrt{s_{NN}} = 200$ GeV d+Au and Au+Au collisions by PHENIX

D. Pal[a] (for the PHENIX* Collaboration)

[a]Vanderbilt University, Nashville, TN 37235, USA

We report the first results of the nuclear modification factors and elliptic flow of the ϕ mesons measured by the PHENIX experiment at RHIC in high luminosity Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The nuclear modification factors R_{AA} and R_{CP} of the ϕ follow the same trend of suppression as π^0's in Au+Au collisions. In d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, the ϕ mesons are not suppressed. The elliptic flow of the ϕ mesons, measured in the minimum bias Au+Au events, is statistically consistent with other identified particles.

1. INTRODUCTION

The study of the ϕ mesons in p+p, d+Au and Au+Au collisions is a tool to address the issue of intermediate and high p_T particle production induced by the cold and hot nuclear medium. The recent data from RHIC showed an enhancement of protons (baryon) compared to the pions (meson) in heavy ion collisions [1]. This enhancement is substantially pronounced compared to p+p collisions. There are puzzles connected with the origin of this observation: is it a mass effect or a baryon-meson effect? The former is predicted by hydrodynamics while the latter is proposed by recombination models [2]. The nuclear modification factors, R_{AA} and R_{CP} and the elliptic flow, v_2, of the ϕ mesons are important observables to address the baryon-meson puzzle at RHIC. The former measures directly the magnitude of a suppression or enhancement while the latter represents the final state interaction measured by the quark-number scaling [3].

The PHENIX experiment at RHIC has measured the ϕ mesons in the recent high luminosity Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The data from Run-3 (2002-2003) d+Au [4] and p+p collisions at $\sqrt{s_{NN}} = 200$ GeV have also been analyzed for the ϕ. We report the nuclear modification measurements in Au+Au and d+Au collisions and the first results on v_2 analysis of the ϕ mesons in the K^+K^- decay channel.

2. $\phi \to K^+K^-$ RECONSTRUCTION

2.1. Data analysis

The PHENIX central arm spectrometer [5] consists of East and West arms where the produced particles are being tracked by the Drift Chamber and Pad Chambers. The

*For the full list of the PHENIX authors and acknowledgements, see Appendix 'Collaboration' of this volume.

kaons are identified by the lead scintillator (PbSc) and time of flight (TOF) subsystems located at the central arm spectrometers within $|\eta| < 0.35$. While the TOF wall covers only a small fraction of the East arm ($\Delta\phi \sim 45°$), the PbSc arrays cover the other half of the East ($\Delta\phi \sim 45°$) and all of the West ($\Delta\phi \sim 90°$) arm. TOF has a better timing resolution than PbSc; the two detectors allow us to identify the kaons within $0.3 < p\,(GeV/c) < 2.0$ and $0.3 < p\,(GeV/c) < 1.0$ with TOF and PbSc, respectively, within 2σ π/K separation bands in the mass-squared distribution.

The results presented here are based on minimum bias and centrality selected datasets with a cut of $|z_{vertex}| < 30$ cm on collision vertex. The nuclear modification results discussed here are based on 170×10^6 and 409×10^6 Au+Au minimum bias events for PbSc and TOF analyses, respectively, along with 43×10^6 p+p minimum bias events. R_{CP} measurements in d+Au collisions were performed with 54×10^6 minimum bias events. The elliptic flow analysis, however, used about 800×10^6 minimum bias Au+Au events.

2.2. Pair analysis and signal extraction

The reconstruction of ϕ mesons takes place in two steps. First, we combine oppositely charged kaons to form unlike sign invariant mass spectrum which has combinatorial background. In the second step, we estimate the combinatorial background by event mixing technique where we combine all K^+'s from one event with all K^-'s from ten other events of the same centrality and vertex class. The validity of this event mixing technique is confirmed with like sign distributions. The unlike sign mixed event mass distribution is then normalized to the measured $2\sqrt{N_{++}N_{--}}$, where N_{++} and N_{--} represent the measured integrals of like sign yields. Finally, the ϕ meson invariant mass spectrum is reconstructed by subtracting the combinatorial background from the same event K^+K^- spectrum. We counted the ϕ mesons within a mass window of $\pm$ 5 MeV/c^2 around the measured centroid. Fig. 1 shows the minimum bias $\phi \to K^+K^-$ invariant mass spectrum in Au+Au collisions (left) and m_T spectra of the ϕ in centrality selected Au+Au and p+p collisions.

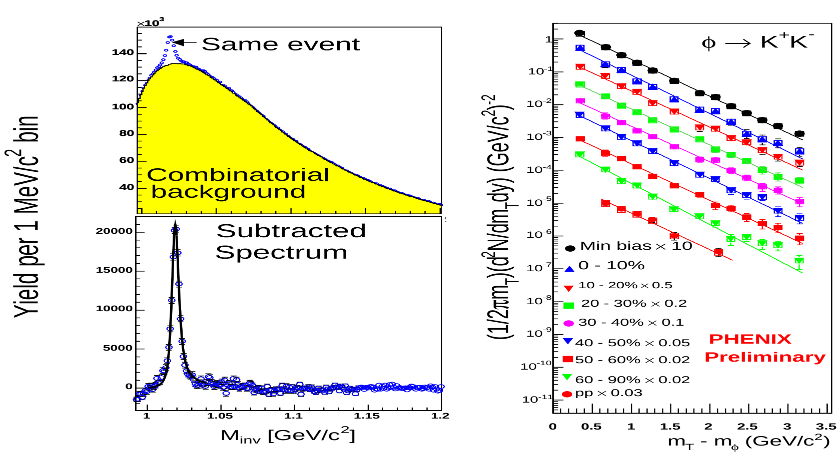

Figure 1. Left: $\phi \to K^+K^-$ invariant mass distributions. Right: $\phi \to K^+K^-$ m_T spectra in Au+Au and p+p datasets at $\sqrt{s_{NN}} = 200$ GeV.

3. RESULTS

3.1. Nuclear Modification factors

The nuclear modification factors, R_{CP} and R_{AA} are defined as:

$$\mathrm{R_{CP}}\ (\mathrm{p_T}) \ = \ \frac{\text{Invariant yield}^{\text{Central}}(\mathrm{p_T})/\mathrm{N_{coll}^{Central}}}{\text{Invariant yield}^{\text{Peripheral}}(\mathrm{p_T})/\mathrm{N_{coll}^{Peripheral}}} \tag{1}$$

$$\mathrm{R_{AA}}\ (\mathrm{p_T}) \ = \ \frac{\text{Invariant yield}_{\text{Au+Au}}(\mathrm{p_T})/\mathrm{N_{coll}}}{\text{Invariant yield}_{\text{pp}}(\mathrm{p_T})} \tag{2}$$

where N_{coll} is the number of binary collisions.

The nuclear modification factor, R_{AA} is plotted as a function of p_T in Fig. 2 (a-b) where we show that the ratio of the ϕ meson yields in (a) central (0 - 10%) and (b) peripheral (60 - 90%) Au+Au to p+p collisions. The proton and π^0 data points are also shown for comparison. The figures show that the ϕ mesons are strongly suppressed and their suppression factor is consistent with the π^0's.

For Au+Au collisions, we calculated R_{CP} as a ratio of N_{coll} scaled ϕ yields in 0 - 10% and 60 - 90% centralities (Fig. 2(c)) whereas for d+Au collisions we took 0 - 20% as the most central and 60 - 88% as the most peripheral bins (Fig. 2(d)). In both Au+Au and d+Au cases, we plotted the results of protons and π^0's for comparison. In Au+Au collision, we also included the R_{CP} of Λ particles. The figure shows the suppression of the ϕ mesons that is consistent with π^0's while there is non-suppression (or even enhancement) of (anti)protons and Λ's in Au+Au collisions. In the cold nuclear matter produced by d+Au collisions, however, we do not observe any suppression of the ϕ mesons.

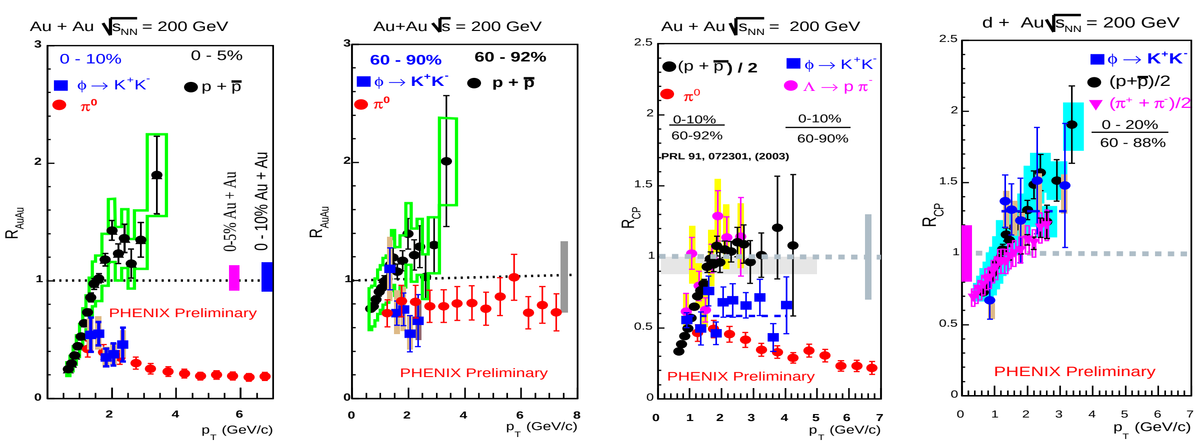

Figure 2. (a) R_{AA} for 0 - 10%, (b) R_{AA} for 60 - 90% centrality Au+Au collisions, (c) R_{CP} in Au+Au and (d) R_{CP} in d+Au collisions. The vertical error bars around R_{AA} or R_{CP} = 1 represent the systematic errors from N_{coll}, the bands around the proton, ϕ, Λ and charged pion data points represent the systematic errors from the yield determination.

3.2. Elliptic flow

The elliptic flow (v_2) is studied by investigating the azimuthal asymmetry of the ϕ meson emission with respect to the event reaction plane as:

$$\frac{dN}{d\phi_0} \ = \ a(1 \ + \ 2\ v_2\ cos2\phi_0) \tag{3}$$

where ϕ_0 is the azimuthal angle of the ϕ mesons with respect to the reaction plane angle of the event. Fig. 3 shows (a) v_2 of the ϕ mesons in minimum bias Au+Au collisions as a function of p_T and (b) quark-number (n) scaled v_2, v_2/n as a function of p_T/n. The elliptic flow parameters for the identified particles are also shown on the plots for comparison. Within the present size of the statistical error at different p_T, both v_2 and v_2/n of the ϕ are consistent with other hadrons.

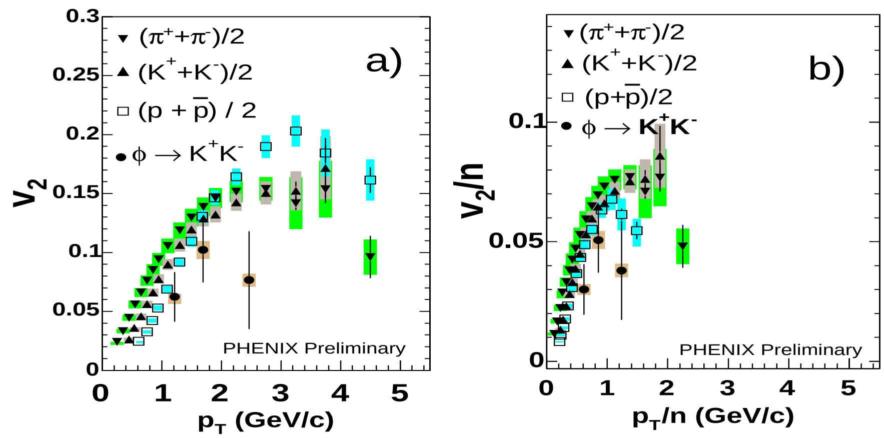

Figure 3. (a) v_2 of the ϕ mesons as a function of p_T, and (b) v_2/n of the ϕ as a function of p_T/n, n being the number of quarks. Other identified hadrons are also plotted for comparison. The bands around the data points represent systematic errors.

4. SUMMARY

The PHENIX experiment at RHIC has measured the nuclear modification factors, R_{CP} and R_{AA} of the ϕ mesons. In Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, the ϕ meson shows similar suppression as the π^0 and therefore follows a completely different trend than the (anti)protons and Λ's. This indicates the presence of a strong constituent quark number effect (baryon/meson effect) compared to the mass effect in particle production at intermediate p_T at RHIC. The d+Au control experiment does not show any suppression effect in R_{CP} of the ϕ, similar to the case for other hadrons.

The elliptic flow of the ϕ mesons has been measured for the minimum bias data sample. Within the present statistical errors the v_2 of the ϕ meson exhibits a non-zero elliptic flow which, if scaled by the quark number, is consistent with the quark number scaled v_2 of the other hadrons.

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