EPJ Web of Conferences **164**, 07057 (2017) DOI: 10.1051/epjconf/201716407057
ICNFP 2016

ϕ Meson Production at Forward Rapidity with the PHENIX Detector at RHIC

Murad Sarsour[1,a] on behalf of the PHENIX Collaboration

[1] *Georgia State University, Atlanta, Georgia 30303, USA*

Abstract. The ϕ meson production in p+p collisions is an important tool to study QCD, providing data to tune phenomenological QCD models, while in high-energy heavy-ion collisions it provides key information on the hot and dense state of the strongly interacting matter produced in such collisions. It is sensitive to the medium-induced effects such as strangeness enhancement, a phenomenon associated with soft particles in bulk matter. Measurements in the dilepton channels are especially interesting since leptons interact only electromagnetically, thus carrying the information from their production phase directly to the detector. Measurements in different nucleus-nucleus collisions allow us to perform a systematic study of the nuclear medium effects on ϕ meson production. The PHENIX detector provides the capabilities to measure the ϕ meson production in a wide range of transverse momentum and rapidity to study various cold nuclear effects such as soft multiple parton rescattering and modification of the parton distribution functions in nuclei.

In this proceeding, we report the most recent PHENIX results on ϕ meson production in p+p, d+Au and Cu+Au collisions.

1 Introduction

Ever since RHIC announced the discovery of the hot and dense state of strongly interacting matter called Quark-Gluon Plasma (QGP) [1, 2], the main objective has been to quantify its properties. This is accomplished by looking at as many observables as possible, such as the nuclear modification of ϕ meson production in the QGP environment. ϕ meson is an excellent probe for studying QGP (in Au+Au collisions) because it is sensitive to several aspects of the collision, including modifications of strangeness production in bulk matter. Owing to its small inelastic cross section for interaction with nonstrange hadrons, the ϕ meson is less affected by late hadronic rescattering and may reflect the initial evolution of the system. Being composed of a nearly pure strange antistrange ($s\bar{s}$) state, the ϕ meson puts additional constraints on models of quark recombination in the QGP. However, to gauge the QGP related modifications, we need to know the ϕ meson production in p+p collisions as a baseline. There are additional effects from the nuclear medium itself and they are accessed by studying ϕ production in d+Au collisions.

The lepton decay channel is of particular interest because of the absence of strong interactions between muons and the surrounding hot hadronic matter. At forward rapidity, it allows us to study the

[a] e-mail: msar@gsu.edu

rapidity dependence of ϕ production and especially in asymmetric heavy-ion collisions provides the means for accessing different mixtures of initial and final state effects.

In p+p collisions, the ϕ meson production is also important to study because it may have similar production mechanisms to other onia like J/ψ and Υ. In addition, it provides a tool to study effects that scale with mass (e.g. collective effects) since it is the heaviest easily accessible meson made of light quarks.

2 Experimental Setup

The PHENIX detector [3] has a high rate capability utilizing a fast DAQ and specialized triggers, high granularity detectors, and good mass resolution and particle ID. The $\mu^{\pm}$ are detected through the forward spectrometers consisting of Muon ID and Muon Tracker. The very forward beam-beam counters (BBC) are used to determine the collision vertex position and time, the beam luminosity and form a minimum bias trigger.

The PHENIX collaboration collected data from a variety of collisions provided by the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). Results from p+p, d+Au and Cu+Au data sets are presented in this proceeding.

3 Results

The differential production cross sections of ϕ meson have been extracted as a function of transverse momentum ($1 < p_T < 7$ GeV/c) and rapidity ($1.2 < |y| < 2.2$), in p+p collisions as shown in Fig. 1 [4]. The results are compared to different PYTHIA tunes and PHOJET [5] simulations. ATLAS-CSC [6] and PHENIX [7] tunes of PYTHIA reproduce the ϕ cross section reasonably well while the other simulations under-predict it by a factor 2.

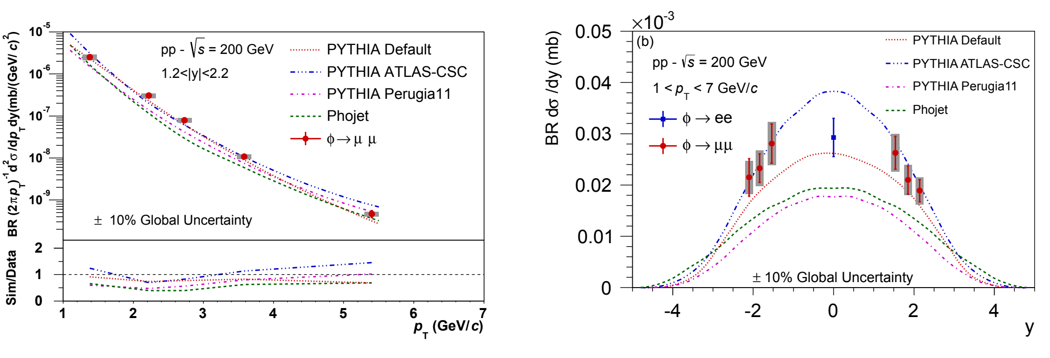

Figure 1. Left: (Top) p_T-dependent differential cross section vs p_T of ϕ at rapidity, $1.2 < |y| < 2.2$. The data are compared with the PYTHIA ATLAS-CSC [6], default [7] and PERUGIA-11 [8] tunes and PHOJET [5]. (Bottom) Ratio between data and models. Right: Rapidity dependent differential cross section of ϕ along with previous PHENIX results [9] summed over the p_T range, $1 < p_T < 7$ GeV. The data are compared with the PYTHIA ATLAS-CSC and PERUGIA-11 tunes and PHOJET. In both panels, the error bars represent the quadratic sum of the statistical uncertainties and point-to-point fluctuating uncertainties, and the gray shaded band represents the quadratic sum of p_T correlated systematic uncertainties.

The left panel of Fig. 2 shows the ϕ meson invariant yield in Cu+Au collisions as a function of the number of participating nucleons, $N_{\rm part}$, while the right panel shows the dependence of the invariant

DOI: 10.1051/epjconf/201716407057

yield on p_T [10]. More ϕ mesons are produced in the Au-going direction ($-2.2 < y < -1.2$) than in the Cu-going direction ($1.2 < y < 2.2$). This may be explained by the larger multiplicity in the Au-going direction coupled with a mixture of both hot nuclear matter (HNM) and cold nuclear matter (CNM) effects.

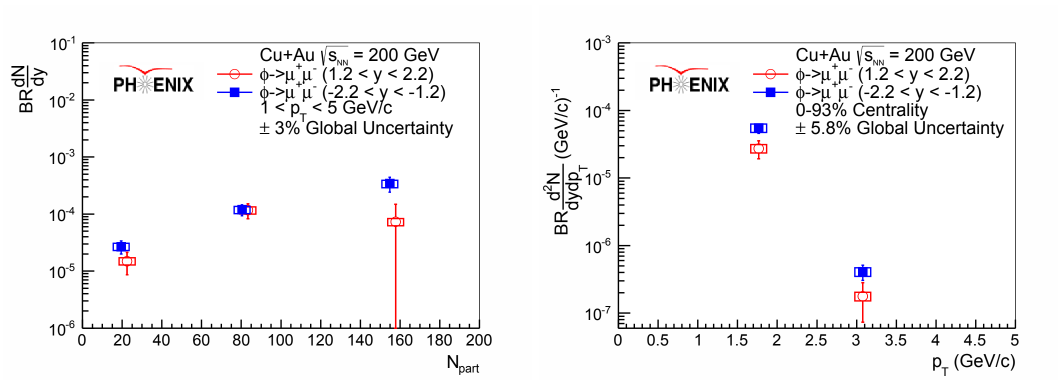

Figure 2. Left: The ϕ meson invariant yield as a function of the number of participating nucleons for $1.2 < |y| < 2.2$ and $1 < p_T < 5$ GeV/c. The data points at $1.2 < y < 2.2$ are shifted along the x-axis to $N_{\text{part}} + 3$ for clarity. Right: The ϕ meson invariant yield as a function of transverse momentum for $1.2 < |y| < 2.2$ and 0%–93% centrality. The Cu-going direction corresponds to the forward rapidity, $1.2 < y < 2.2$, while the Au-going direction corresponds to the backward rapidity, $-2.2 < y < -1.2$.

To gain insight into nuclear medium effects and particle production mechanisms in A+B collisions, the ratio of the ϕ meson yields in A+B collisions to p+p collisions scaled by the number of nucleon-nucleon collisions in the A+B system, N_{coll} [11], is calculated as:

$$R_{AB} = \frac{d^2N_{AB}/dydp_T}{N_{\text{coll}} \times d^2N_{pp}/dydp_T}, \tag{1}$$

where $d^2N_{AB}/dydp_T$ is the per-event yield of particle production in heavy ion collisions and $d^2N_{pp}/dydp_T$ is the per-event yield of the same process in p+p collisions. The p+p invariant yield used in the A+B calculation for the $\mu^+\mu^-$ decay channel is the p+p differential cross section divided by the p+p total cross section, 42.2 mb.

Figure 3 shows the ϕ meson $R_{d\text{Au}}$ as a function of p_T for different centralities [12]. The observed nuclear modification is very similar to that of the heavy flavor muons [13]. In most central collisions, a significant enhancement in the Au-going direction is observed that is more pronounced at intermediate p_T, a characteristic of the Cronin effect [14], while in the d-going direction a suppression at low-p_T is observed. However, in the peripheral collisions no modification is observed. At midrapidity, the $R_{d\text{Au}}$ remains consistent with unity for p_T above 1 GeV/c. This is consistent between the measurements done in the e^+e^- and in the K^+K^- decay channels. The ϕ meson enhancement in the Au-going direction and the suppression in the d-going direction are consistent with what is observed by ALICE in p+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV in $-4.46 < y < -2.96$ and $2.03 < y < 3.53$ [15].

The ϕ meson $R_{d\text{Au}}$, measured as a function of rapidity, is compared with that of heavy flavor leptons [13, 16] and J/ψ meson [11, 17], as shown in Fig. 4 [12]. It is very interesting to observe the similarity with the nuclear modification of heavy flavor quark production given that the heavy flavor quark production is expected to be dominated by hard processes over the accessed p_T range. In

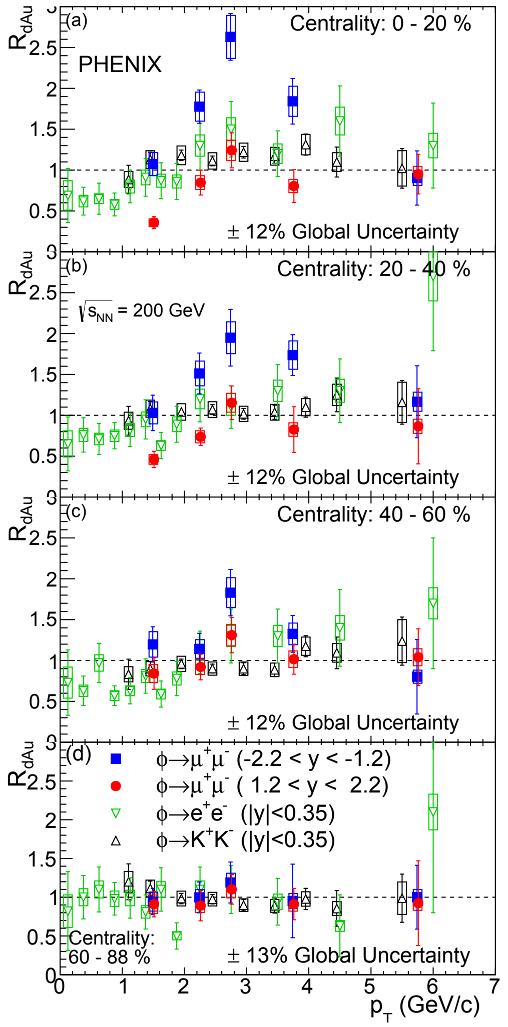

Figure 3. The ϕ meson R_{dAu} as a function of p_T for the shown centrality classes in the Au-going direction (solid blue squares) and the d-going direction (solid red circles). At midrapidity, the upright black triangles are from $\phi \to K^+K^-$ while the upside down triangles are from $\phi \to e^+e^-$. The ±12%–13% uncertainty is the associated global scaling uncertainty.

contrast, one expects a significant contribution to ϕ meson production from soft processes, particularly at low p_T where the yield is dominant. This enhancement (suppression) in the Au-going (d-going) direction is also observed in d+Au charged hadron density results measured by PHOBOS [18]. The pattern observed in the charged hadron measurement is often considered as a result of a rapidity shift in the Au-going direction via soft processes [19]. Figure 4 also shows that the J/ψ meson suffers from additional suppression at backward and midrapidity relative to the ϕ meson and heavy-flavor decay leptons. These differences could be attributed to a larger J/ψ break up cross section, effects

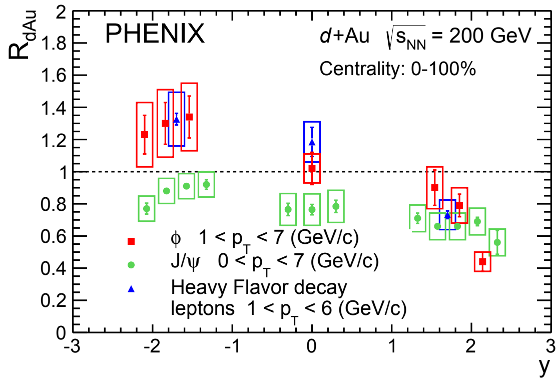

Figure 4. J/ψ meson (solid green circles), heavy flavor decay leptons (solid blue triangles) and ϕ meson (solid red squares) nuclear modification factors, $R_{d\mathrm{Au}}$, as a function of rapidity. The global scaling systematic uncertainties associated with heavy flavor and J/ψ meson measurements are 10% and 8%, respectively.

in the higher energy- density backward-rapidity region, or changes between soft and hard production mechanisms between the two mesons.

The nuclear-modification factor is also studied to evaluate the effects of hot and cold nuclear matter on ϕ meson production in Cu+Au collisions at $\sqrt{s_{NN}}$= 200 GeV. The nuclear-modification factor as a function of N_{part} is shown in the left panel of Fig. 5 [10]. There is a dependence of R_{CuAu} on both centrality and rapidity. In the Au-going direction, the R_{CuAu} is greater than unity for all centralities. The rapidity dependence has a similar trend to that observed in d+Au collisions, as well as measurements made by ALICE in p+Pb collisions at 5.02 TeV [15]. To further understand the

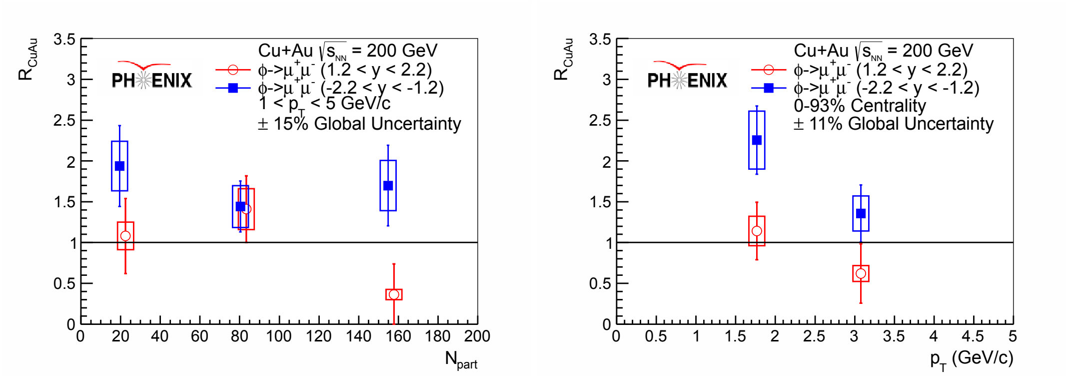

Figure 5. Left: The nuclear-modification factor R_{CuAu} as a function of the number of participating nucleons for $1.2 < |y| < 2.2$ and $1 < p_T < 5$ GeV/c. The data points at $1.2 < y < 2.2$ are shifted along the x-axis to $N_{\mathrm{part}} + 3$ for clarity. Right: The nuclear-modification factor R_{CuAu} as a function of transverse momentum for $1.2 < |y| < 2.2$ and 0%–93% centrality.

relative roles of different nuclear matter effects in this collision system, the transverse momentum dependence of the nuclear-modification factor is shown in the right panel of Fig. 5. Here the nuclear modification is calculated over integrated centrality, but it should be noted that the data are dominated by central collisions. There is an enhancement at low p_T in the Au-going direction. In the Cu-going direction, R_{CuAu} is consistent with unity. The enhancement in the Au-going direction is similar in scale to that observed in the Au-going direction in d+Au collisions [12], indicating similar nuclear modification between the two collision systems.

Figure 6 shows the nuclear modification factor R_{CuAu} as a function of rapidity [10]. The rapidity dependence of R_{CuAu} shows a similar trend to that observed in the case of $p(d)$+Au collisions, shown in Fig. 4. The J/ψ meson yield is strongly suppressed in the Au-going direction compared to the ϕ

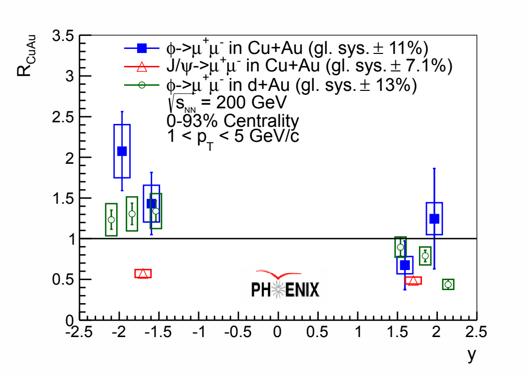

Figure 6. The nuclear modification factor R_{CuAu} as a function of rapidity for $1 < p_T < 5$ GeV/c and 0%–93% centrality. Also included are previous PHENIX results for ϕ mesons in d+Au collisions [12] represented by open circles and J/ψ mesons in Cu+Au collisions [20] represented by open triangles.

meson yield at the same rapidity. This is similar to the differences previously observed between J/ψ and ϕ meson nuclear modification in d+Au collisions [12].

4 Summary and Outlook

The PHENIX collaboration measured the ϕ meson production, over a wide p_T range in the forward and backward rapidities in d+Au and Cu+Au collisions to study cold and hot nuclear matter effects. In d+Au collisions, we observed an enhancement (suppression) of the ϕ meson at backward (forward) rapidity region in most central collisions. Similar behavior was previously observed for inclusive charged hadrons and open heavy flavor muons which may suggest similar cold nuclear matter effects. In Cu+Au collisions, there is an enhancement over all centralities in the Au-going direction, while a suppression is observed for the most central collisions in the Cu-going direction. A comparison with the J/ψ meson in both d+Au and Cu+Au collisions shows different modification in Au-going direction which suggests that the ϕ meson follows a different production mechanism.

New data sets from p+Au and p+Al collisions collected in 2015 will allow ϕ measurement at backward and forward rapidities in less complicated p+Au and p+Al systems. The wealth of small system data sets (d+Au, p+Au and p+Al) along with the introduction of the forward vertex detector (FVTX) in 2015 data sets will allow studying the different CNM effects using models like AMPT and EPOS.

References

[1] K. Adcox *et al.* (PHENIX Collaboration), Nucl. Phys. A **757**, 184 (2005).
[2] J. Adams *et al.* (STAR Collaboration), Nucl. Phys. A **757**, 102 (2005).
[3] K. Adcox *et al.* (PHENIX Collaboration), Nucl. Instrum. Methods Phys. Res., Sec. A **499**, 469 (2003).
[4] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. D **90**, 052002 (2014).
[5] R. Engel and J. Ranft, Phys. Rev. D **54**, 4244 (1996).
[6] C. Buttar *et al.*, Acta Phys. Pol. B **35**, 433 (2004).
[7] T. Sjostrand *et al.*, Comput. Phys. Commun. **135**, 238 (2001).
[8] P. Z. Skands, Phys. Rev. D **82**, 074018 (2010).
[9] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. D **83**, 052004 (2011).
[10] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. C **93**, 024904 (2016).
[11] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. C **87**, 034904 (2013).
[12] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. C **92**, 044909 (2015).
[13] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. Lett. **112**, 252301 (2014).
[14] J. W. Cronin, H. J. Frisch, M. J. Shochet, J. P. Boymond and R. Mermod, *et al.*, Phys. Rev. C **11**, 3105 (1975).
[15] J. Adam *et al.* (ALICE Collaboration), arXiv:1506.09206.
[16] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. Lett. **109**, 242301 (2012).
[17] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. Lett. **107**, 142301 (2011).
[18] B. B. Back *et al.* (PHENIX Collaboration), Phys. Rev. C **72**, 031901 (2013).
[19] B. B. Back *et al.*, Phys. Rev. Lett. **93**, 082301 (2004).
[20] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. C **90**, 064908 (2014).