STUDY OF LIGHT VECTOR MESONS AT RHIC BY PHENIX

PNPI participants of the PHENIX Collaboration:
V.V. Baublis, D.A. Ivanischev, A.V. Khanzadeev, B.G. Komkov, V.G. Ryabov, Yu.G. Ryabov, V.M. Samsonov, E.A. Vznuzdaev, M.B. Zhalov

1. Introduction

Light vector mesons are among the most interesting probes of the matter created in relativistic heavy ion collisions. The simultaneous measurement of meson properties in *p*+*p*, *d*+Au and Au+Au collisions provides a basis for the observation of anomalous features specific to heavy ion collisions and allows separation of cold and hot nuclear effects affecting particle production.

One of the most exciting measurements performed by all experiments at RHIC was the observation of suppression of high transverse momentum hadrons in central Au+Au collisions. Later it was found that baryons (protons) and light mesons (π^0) have different suppression tendencies that brought up the "baryon puzzle" [1]. Measurement of nuclear modification factors for vector mesons adds to the picture of particle suppressions and their dependence on particle mass and composition supporting hydrodynamics or recombination models.

Properties of the light vector mesons are sensitive to the chiral symmetry restoration expected to occur at sufficiently high temperatures achieved in heavy ion collisions. Short lifetimes of ω and φ-mesons (Γ_ω = 8.5 MeV, Γ_φ = 4.3 MeV) presuppose that significant part of them decays inside the hot and dense nuclear matter produced in heavy ion collisions. Theoretical models predict that basic properties of the light vector mesons such as mass, width and branching ratios can be modified in presence of this media. Such modifications can be studied by comparison of meson properties measured in leptonic and hadronic decay modes in different collision systems.

2. Experimental setup and data samples

The two central spectrometers of the PHENIX experiment [2] each covering 90° in azimuth and ±0.35 in pseudorapidity have a capability to measure both neutral and charged particles produced in RHIC collisions (see Fig. 1). Beam-Beam Counters and Zero Degree Calorimeters provide the minimum bias trigger and are

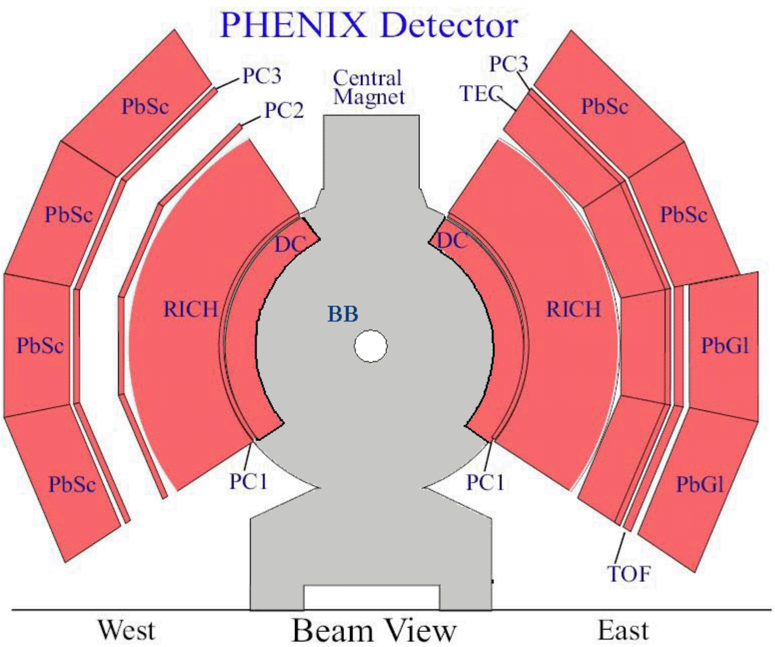

Fig. 1. Layout of the PHENIX central spectrometer

used to determine Z-coordinate of the collision vertex and the event centrality. The momentum of charged particles is measured with the Drift Chamber (DC) and the first layer of the Pad Chamber (PC1). In some cases the third layer of the Pad Chambers (PC3) is used for track confirmation. For hadron identification PHENIX has a high resolution TOF subsystem covering about half of the East arm ($|\eta| < 0.35$ and $\Delta\varphi \sim 45°$) and an Electromagnetic Calorimeter (EMC: PbSc and PbGl) covering both arms. The TOF subsystem and time of flight of the EMC identify kaons within $0.3 < p$[GeV/c] < 2.0 and $0.3 < p$[GeV/c] < 1.0, respectively. The electrons are identified with a Ring Imaging Cherenkov Detector (RICH) and by matching of energy measured in the EMC and momentum measured in the DC for the charged track. The EMC is also used as a primary detector for the reconstruction of photons and π^0-mesons [3].

For hadron decays of ω-mesons minimum bias and ERT data samples are used. The latter sample was accumulated with high-p_T online trigger realized by adding together amplitudes in 4 × 4 adjacent EMC towers and comparing them to a threshold of 1.4 GeV in p+p and 2.4 GeV in d+Au collisions. Analyzed decays, basic analysis cuts and data samples are presented in Table.

Table

Decay	Vertex, cm	PID	Data Sample, events
$\varphi \to e^+e^-$	$-28 < Z < 26$	RICH, EMC	Run 4, (Au+Au, 200 GeV): 9×10^8 MinBias
$\varphi \to K^+K^-$	$-30 < Z < 30$	TOF (EMC)	Run 4, (Au+Au, 200 GeV): 4.1 (1.1) $\times 10^8$ MinBias Run 3, (p+p, 200 GeV): 4.3×10^7 MinBias Run 3, (d+Au, 200 GeV): 5.4×10^7 MinBias
$\omega \to e^+e^-$	$-25 < Z < 25$	RICH, EMC	Run 4, (Au+Au, 200 GeV): 8×10^8 MinBias
$\omega \to \pi^0\pi^+\pi^-$	$-30 < Z < 30$	No PID	Run 5, (p+p, 200 GeV): 1.5×10^9 MinBias and 10^9 ERT (5.7×10^{10} sampled MinBias) Run 3, (d+Au, 200 GeV): 2.1×10^7 ERT (3.1×10^9 sampled MinBias)
$\omega \to \pi^0\gamma$	$-30 < Z < 30$	No PID	Run 5, (p+p, 200 GeV): 1.5×10^9 MinBias and 10^9 ERT (5.7×10^{10} sampled MinBias) Run 4, (Au+Au, 200 GeV): 7.8×10^8 MinBias Run 3, (d+Au, 200 GeV): 2.1×10^7 ERT (3.1×10^9 sampled MinBias)

3. Analysis

For the reconstruction of $\varphi(\omega) \to e^+e^-$ and $\varphi \to K^+K^-$ decays we combine oppositely charged identified particles to form unlike sign invariant mass spectra containing both the signal and combinatorial background of uncorrelated pairs. The shape of the uncorrelated combinatorial background is estimated in mixed event technique where identified particles of one sign are combined with particles of the opposite sign taken from several other events having the same centrality and collision vertex. The mixed event invariant mass distribution is then normalized to the value of $2\sqrt{N_{++}N_{--}}$ where N_{++} and N_{--} are the measured integrals of like-sign yields. The validity of this method of event mixing was confirmed by comparing the like-sign invariant mass spectra from mixed events [4]. Raw yields are extracted by the subtraction of mixed event distributions from invariant mass spectra and counting the particle yields around the known masses of particles. In the hadronic decay modes one can see a prominent peak in the mass distributions of the measured mesons but in the di-electron modes it is challenging because of huge combinatorial background originating primarily from the conversion and Dalitz decays of π^0-mesons. For example, in Run 4 data sample the signal-to-background ratio in the range of ω and φ-meson masses is about 1:500.

To measure hadron decays of the ω-mesons we start with reconstruction of π^0-mesons in the $\pi^0 \to \gamma\gamma$ decay channel using EMC. For the $\omega \to \pi^0\gamma$ decay we combine selected π^0-candidates with all other photons from the same event. In case of the $\omega \to \pi^0\pi^+\pi^-$ decay we combine π^0-candidates with any pair of negatively and positively charged tracks assuming them to be π-mesons. Integrals of peaks reconstructed in invariant mass distributions are extracted by fitting since mixed event technique does not reproduce background shape due to presence of residual correlations [5]. In Au+Au collisions we loose the possibility to detect ω-meson in the $\omega \rightarrow \pi^0\pi^+\pi^-$ channel because four particles in the final state produce too much combinatorial background. However even in the most central collisions we can still extract ω-meson yield in the $\omega \rightarrow \pi^0\gamma$ decay at very high p_T.

Extracted raw yields of vector mesons are corrected for detector acceptance and trigger efficiencies evaluated with full Monte Carlo simulation of the PHENIX layout, detector responses, kinematics of particular decays and online trigger settings. For three-body decay of ω-meson we also take into account a non-uniform population of the phase space.

4. Results

The invariant m_T spectra of the φ-mesons in p+p, d+Au and Au+Au collisions at $\sqrt{s_{NN}}$ = 63 and 200 GeV are shown in Fig. 2. The PHENIX has an extensive set of $\varphi \rightarrow K^+K^-$ measurements in time-of-flight region for different collision systems and event centrality bins and also has a preliminary measurement of φ-meson production in the $\varphi \rightarrow e^+e^-$ channel with the results consistent with the hadronic channel. The latter, however, is rather limited because of small signal-to-background ratio.

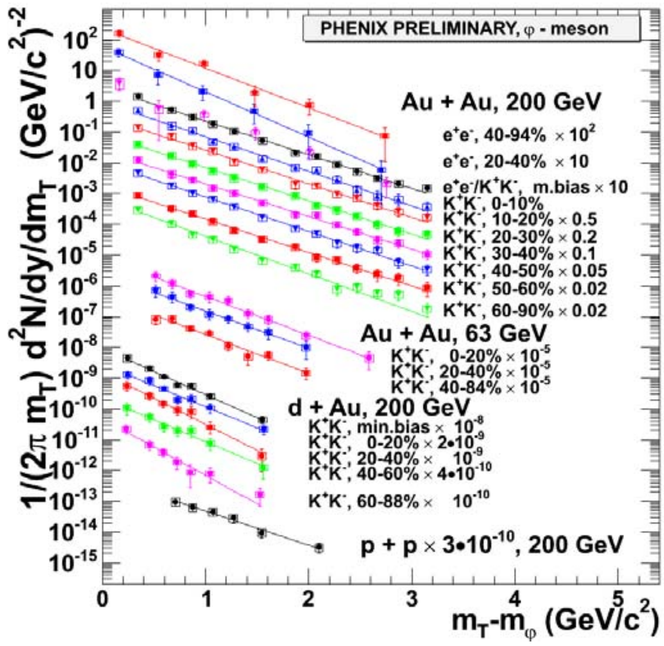

Fig. 2. Transverse mass spectra measured for φ-mesons in p+p, d+Au and Au+Au collisions at $\sqrt{s_{NN}}$ = 63 GeV and $\sqrt{s_{NN}}$ = 200 GeV

The measured m_T spectra were fit to the exponential function to extract integrated yields (dN/dy) and temperatures (T):

$$\frac{1}{2\pi m_T}\frac{d^2N}{dm_T\,dy} = \frac{dN/dy}{2\pi T(T+M_\phi)}\exp\frac{-(m_T-M_\phi)}{T}.$$

Dependence of the measured temperature and integrated yield per pair of participating nucleons on the system size is shown in Fig. 3. The extracted temperatures do not change among different collision systems at the same energy and only slightly grow between 63 GeV and 200 GeV. Also there is no indication that the measured temperature is different in hadronic and leptonic channels. The integrated φ-meson yield per participant increases by approximately a factor of two from peripheral to central collisions at full RHIC energy. Similar growth is also observed at $\sqrt{s_{NN}}$ = 63 GeV. Preliminary measurement of the yields in the leptonic channel looks higher than in $\varphi \to K^+K^-$ channel. However, statistical and systematic uncertainties prevent us from making a conclusive statement on this subject.

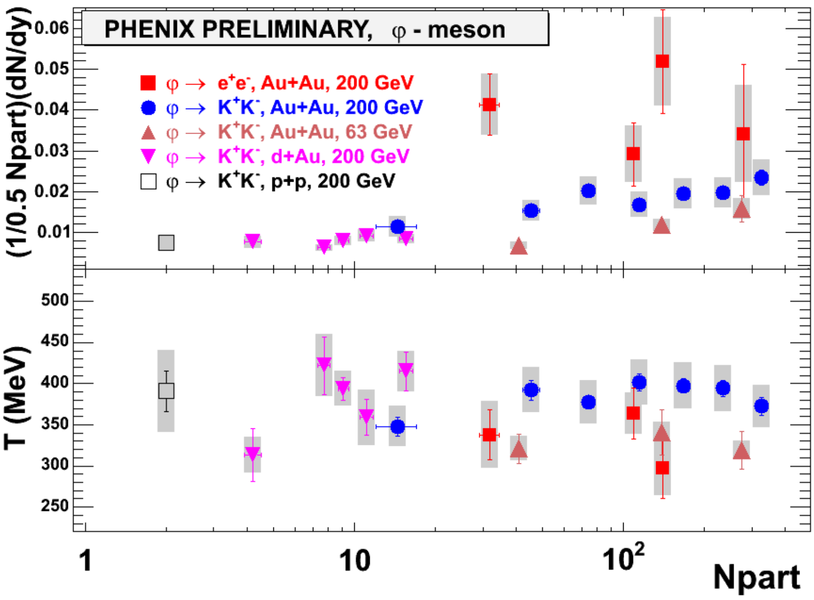

Fig. 3. φ-meson inverse slop (bottom panel) and integrated yield per pair of participants (top panel) as a function of centrality

The invariant p_T spectra measured for ω-mesons in $p+p$, d+Au and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV are shown in Fig. 4. For two hadronic decays $\pi^0\pi^+\pi^-$ and $\pi^0\gamma$ having different kinematics and reconstruction efficiencies we have a very good agreement in $p+p$ and d+Au. In Au+Au collisions we measured three p_T points in each most central, minimum bias and peripheral collisions in the $\pi^0\gamma$ channel. In the di-electron channel the PHENIX has preliminary measurement of ω-meson production at low p_T.

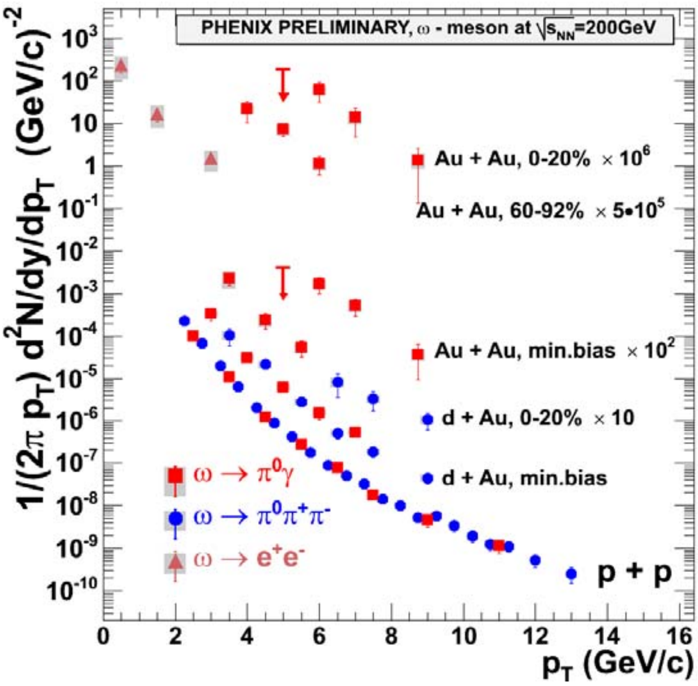

Fig. 4. ω-meson p_T spectra measured in $p+p$, d+Au and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

Figure 5 shows nuclear modification factors (R_{AA}) defined as the ratio of particle yields in Au+Au and *p*+*p* collisions scaled by the number of binary collisions, measured for ω and φ-mesons. In peripheral Au+Au collisions meson yields scale from *p*+*p* yields by the number of binary collisions. But in most central collisions we observe a suppression on the level of 3–5. Such a suppression pattern is consistent within errors with results previously obtained for π^0 mesons [6].

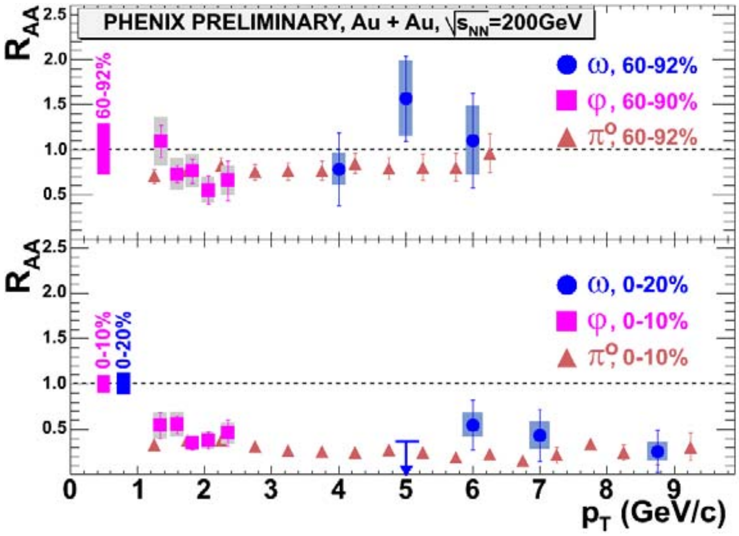

Fig. 5. R_{AA} for φ and ω mesons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

Short living light mesons are considered a good probe of chiral symmetry restoration which can be seen as modification of meson properties in leptonic channels in heavy ion collisions [7, 8]. Besides, some recent publications suggest that modification of meson masses can also be observed in hadronic decays and not only in heavy ion but also in *p*+*p* collisions. Dependence of the mass and width of φ-mesons reconstructed in the $\varphi \to K^+K^-$ decay channel on the centrality in *d*+Au and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV is shown in Fig. 6. The PHENIX experiment sees no modification of the φ-meson mass or width measured in

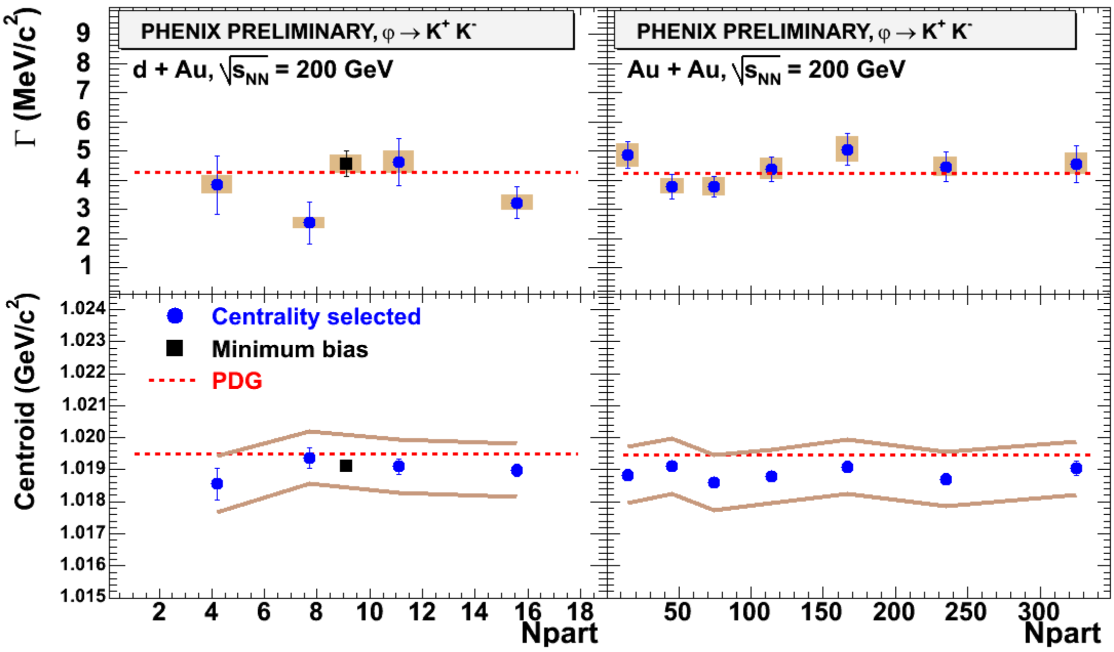

Fig. 6. φ-meson mass and width *vs* centrality in *d*+Au and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

hadronic channels. In $p+p$ and d+Au collisions within the errors of the measurement [4] we find that the reconstructed ω-meson mass is in agreement with PDG value at p_T > 2.5 GeV/c (Fig. 7).

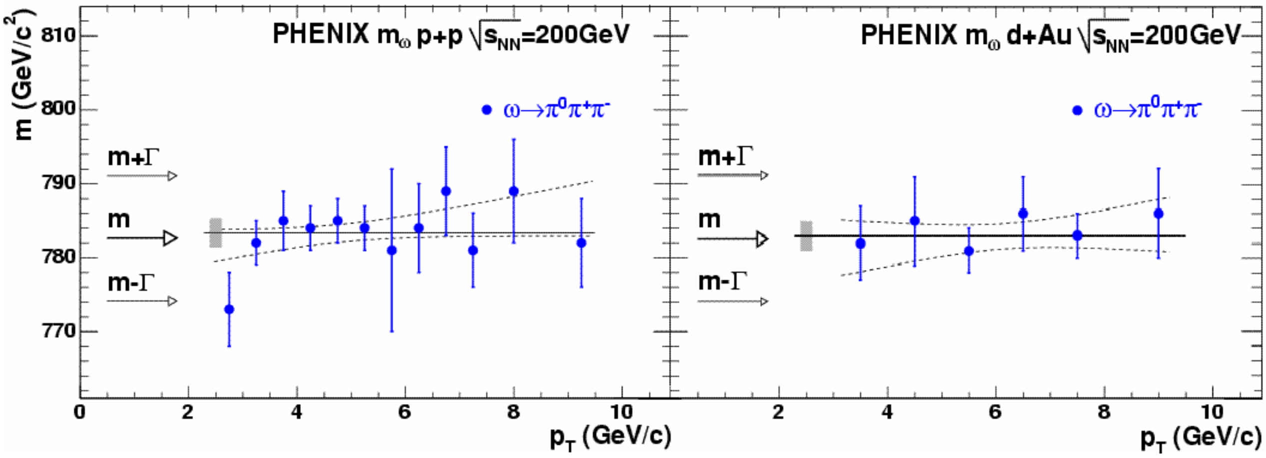

Fig. 7. Reconstructed in $p+p$ (lower panel) and d+Au (upper panel) collisions ω-meson mass versus p_T

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