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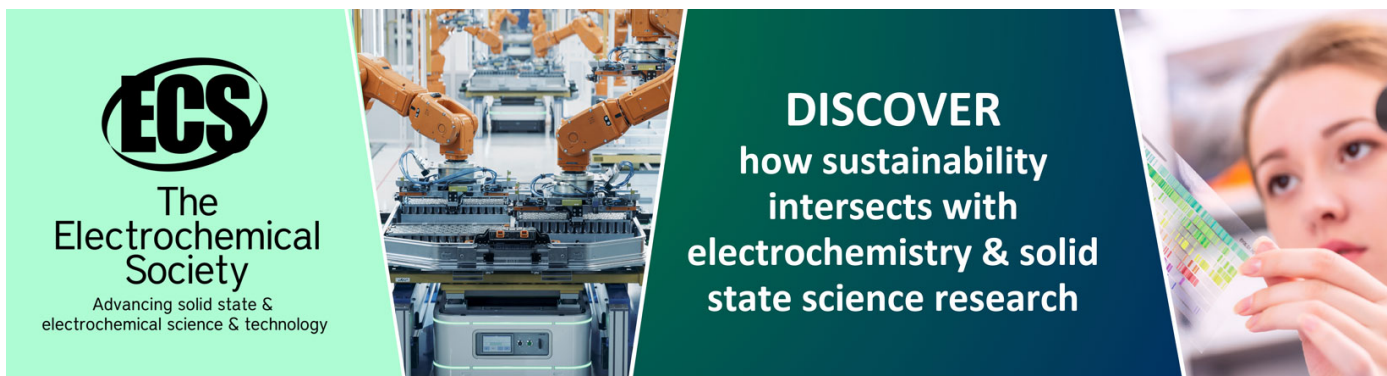
Measurement of ϕ and ω at RHIC-PHENIX

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Measurement of ϕ and ω at RHIC-PHENIX

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Abstract. The PHENIX experiment at RHIC measured the production of ω and ϕ mesons via both leptonic and hadronic decay modes in p+p, d+Au, Cu+Cu and Au+Au at C.M.S. collision energy per nucleon pair of 200 GeV. The recent systematic measurements of these mesons are shown and discussed.

1. Introduction

The measurement of hadrons under extreme conditions created by relativistic heavy-ion collisions is an intriguing study being carried out as a part of the quest to observe the QCD phase transition to Quark Gluon Plasma (QGP) [1].

RHIC provided systematic measurement of hadrons in p+p, d+Au, Cu+Cu and Au+Au. Solid baseline results in p+p, d+Au and comparison study of the invariant yield measurement in heavy-ion collisions suggested that the particle production is effected by jet quenching which is considered to be an effect of the matter created by heavy-ion collisions [2]. Low mass vector mesons, ϕ and ω are one of the interesting probes for the systematic study of hadron suppression to understand particle production mechanism in heavy-ion collisions.

Another possible study of low mass vector mesons is to see partial chiral symmetry restoration via mass and/or branching ratios modification. Especially in low transverse momentum region, a significant number of mesons decay inside the medium since ω and ϕ mesons have short lifetimes, 23 and 46 fm/c respectively. Several theoretical calculations predicted [3][4][5] properties (mass and/or width) are modified in either a hot or dense nuclear medium.

By using both leptonic and hadronic decay modes for the ϕ and ω measurement, PHENIX can cover wide kinematic range (low p_T by the leptonic decay mode and high p_T by hadronic decay mode). thus able to address a number of interesting physics topics.

In this article, we present recent results of the systematic measurement of ϕ by using e^+e^- for leptonic and K^+K^- for hadronic decay mode, and ω by using e^+e^- for leptonic and $\pi^0\gamma, \pi^+\pi^-\pi^0$ for hadronic decay mode in p+p, d+Au, Cu+Cu and Au+Au collected in 2003-2008.

2. Experimental Setup

RHIC provided various collisions of a broad range of nuclear species from proton, deuteron to Cu and Au ions at energies up to $\sqrt{s_{NN}}=200$ GeV. The PHENIX is designed specifically to measure electromagnetic probes of the collisions such as electrons, muons and photons using multi-purpose detectors [6]. The setup of the PHENIX experiment can be grouped into three categories; global detectors close to the beam pipe, 2 muon arms which have pseudo-rapidity coverage of $\pm(1.2-2.4)$ and 2 central arms which has pseudo-rapidity coverage of ± 0.35 , each subtending 90 in azimuthal angle.

Global detectors, beam-beam counters (BBC) and zero degrees calorimeters (ZDC) measure the vertex and centrality of the interactions. Central arms are capable of measuring a variety of particles by Ring Imaging Cerenkov detectors (RICH) for the separation of electrons, Drift Chambers (DC) and Pad Chambers (PC) for the tracking of charged particles and the measurement of their momentum, by Electro Magnetic Calorimeter(EMCal) for the measurement of spatial positions and energies of photons and electrons. EMCal comprises six sectors of Lead Scintillator Calorimeter(PbSc) and two sectors of Lead Glass Calorimeter (PbGl), which have an energy resolution of $\sigma_{PbSc}(E)/E \approx 2.1\% \oplus 8.1\%/\sqrt{E(GeV)}$ and $\sigma_{PbGl}(E)/E \approx 0.8\% \oplus 5.9\%/\sqrt{E(GeV)}$, respectively.

3. Analysis

3.1. Leptonic analysis

Electrons and positrons are identified mainly by the Čerenkov photons emitted in the RHIC. An energy-momentum match between the momentum measured by the tracking system and the energy measured in EMC is required to be within 2 times the resolution of the EMC. Finally the time-of-flight as measured by the EMC was required to be consistent with the flight time of an electron (10 ns $\sim$ 25 ns). The uncorrelated combinatorial background can be explicitly calculated by use of a mixed event technique, by taking candidate tracks from different events [7].

Figure 1 and 2 show an invariant mass spectrum of e^+e^- pairs in p+p, d+Au and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV after subtracting the combinatorial background. The solid line shows the fit of the ϕ , ω , ρ with widths fixed to the PDG values. Underneath the ω in p+p, we fit a ρ component with mass 770 MeV/c² and width of $\Gamma=150$ MeV/c² (cyan line) where we assume ω and ρ have the same yield and have the same branching ratios as in vacuum.

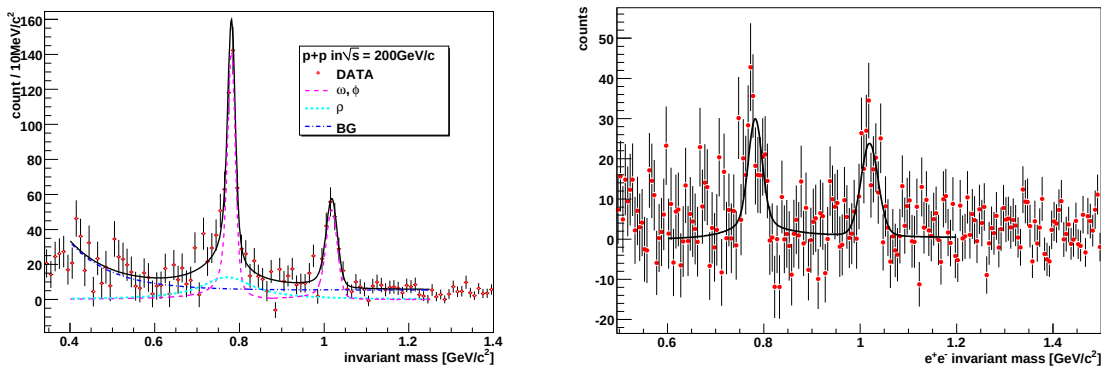


Figure 1. Invariant mass of e^+e^- pairs detected in p+p (left) [10] and d+Au collisions (right) [9]. Breit-Wigner fit to the ϕ and ω resonance is made with the resonance natural width set to the PDG values. The contribution from the residual background (blue line) and the estimated ρ contribution (assuming the same yield as the ω)(light blue) are also included in the fit.

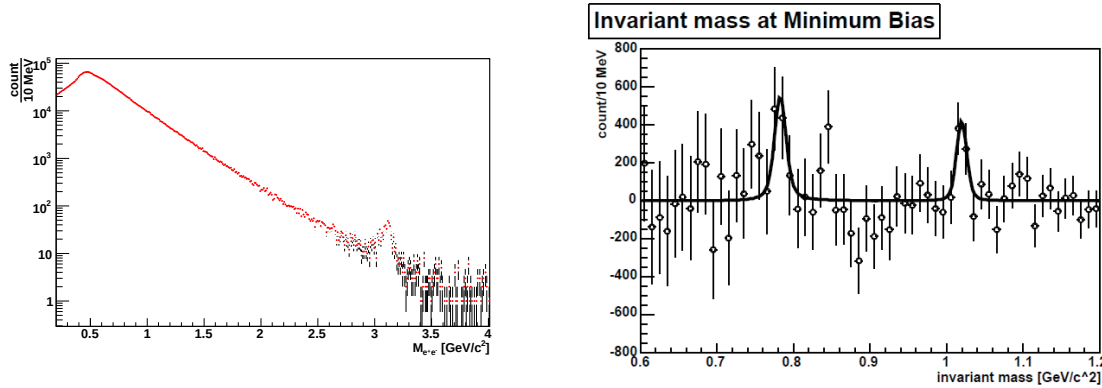


Figure 2. Invariant mass of e^+e^- pairs detected in Au+Au collisions before (left) and after (right) subtracting combinatorial background [9]. Breit-Wigner fit to the ϕ and ω resonance is made with the mass and width set to the PDG values.

In the baseline measurements in p+p and d+Au collisions, clear peaks of ϕ and ω are observed thanks to good momentum resolutions (≈ 10 MeV/c), however, the statistical significance of the peaks in Au+Au collisions is only marginal to discuss mass modification.

3.2. Hadronic analysis

In $\phi \rightarrow K^+K^-$ channel, charged kaons are identified using a combination of the momentum measured by the tracking system and the timing from the TOF. Three techniques were used to reconstruct the invariant mass; explicitly requiring particle ID for both kaon, for only one kaon and without particle ID for both kaons [7] [8]. For the Au+Au data, a mixed event technique was used to subtract combinatorial background.

In $\omega \rightarrow \pi^+\pi^-\pi^0$ and $\omega \rightarrow \pi^0\gamma$ channel, first analysis step is to reconstruct π^0 candidates by combining photons pairs and applying a p_T -dependent cut around the mass of the π^0 . Candidates (which include combinatorial background) are combined with a third photon for $\omega \rightarrow \pi^0\gamma$ or with two unidentified charged tracks (assumed to be π mesons) for $\omega \rightarrow \pi^+\pi^-\pi^0$. Due to high multiplicity and low S/B associated with it, cut optimization was performed in case of Au+Au analysis. Also, background subtraction is executed mixed by estimating three background sources; correlated background (for example, $\pi^0\gamma$ pairs from one of the photons from true π^0 or η making a fake π^0 candidate), uncorrelated background which comes from the combination of independent 3γ s, and K_s^0 contribution ($K_s^0 \rightarrow \pi^0\pi^0 \rightarrow 4\gamma$ s), then each amount of background is determined by fitting.

In p+p and d+Au analysis, raw yields are extracted by a Breit-Wigner convoluted with a Gaussian fitting to the p_T slices of the invariant mass distribution shown in the Figure 3 (widths are about 5 MeV/ c^2 for ϕ and about 9 MeV/ c^2 for ω). The Figure 4 shows the invariant mass distribution in Au+Au analysis with(a) and without(b) combinatorial background. Combinatorial backgrounds are estimated by a mixed event technique which is explained previously.

For both leptonic and hadronic analyses, the extracted raw spectra are corrected for geometrical and reconstruction efficiency to produce the final yield. The efficiency is determined using a full GEANT simulation of the PHENIX detector. For electron-RHIC triggered (ERT) data sample, additional bias for this trigger was estimated by simulated Minimum Bias event sample with applying the same trigger requirements as the ERT.

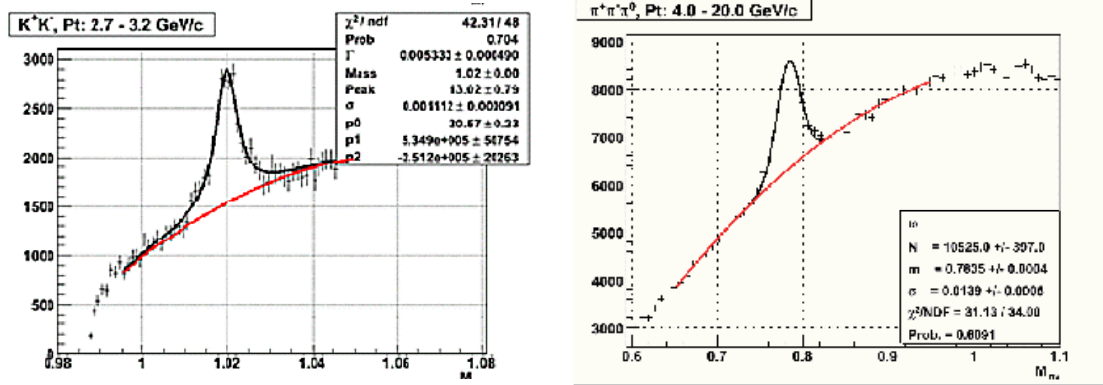


Figure 3. Example of invariant mass distribution in the $\phi \rightarrow K^+K^-$ in d+Au (left) and $\omega \rightarrow \pi^+\pi^0\pi^-$ in p+p (right). A Breit-Wigner convoluted with a Gaussian fit was performed.

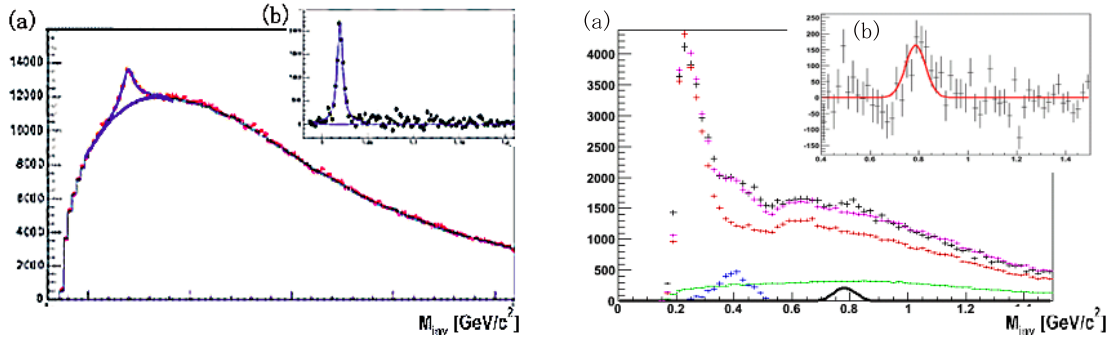


Figure 4. Invariant mass distribution in Au+Au for $\phi \rightarrow K^+K^-$ (left) and $\omega \rightarrow \pi^0\gamma$ (right) before (a) and after (b) subtracting combinatorial background. Combinatorial background is estimated by event-mixed technique (see text).

4. Results

Figure 5 shows invariant cross section for ϕ and ω production in p+p and minimum bias d+Au at $\sqrt{s_{NN}}=200$ GeV, as a function of p_T . Figure 6 shows invariant yield in Au+Au at $\sqrt{s_{NN}}=200$ GeV for ϕ and ω in different centrality; 0-20%, 20-40%, 40-92% and MB for ϕ spectra and 0-20%, 20-60%, 60-92% and MB for ω spectra. The spectra in p+p are fitted by a Levy function[15] (solid lines in the plots) and scaled by the expected N_{coll} for each collision (dashed lines in the plots). Although some points of $\phi \rightarrow e^+e^-$ at low p_T in p+p and d+Au may have a questionable divergence compared to the fitted line in ϕ spectra, overall spectra of ϕ and ω in p+p and d+Au are consistent within the errors. In Au+Au collisions, no signature of mass modification is observed beyond the errors, as shown in the Figure 6. The difference, if any, between the two decay modes is to be quantified via careful examination of centrality dependences of integrated yields, transverse momentum slopes and the spectra themselves.

Figure 7 shows nuclear modification factor, R_{dAu} for ϕ and ω as a function of p_T in minimum bias d+Au. Data for ϕ shown with both $\phi \rightarrow e^+e^-$ and $\phi \rightarrow K^+K^-$ (left) and ω with both $\omega \rightarrow e^+e^-$ and $\omega \rightarrow \pi^0\gamma$ (right). All R_{dAu} are consistent within errors and there are no significant signature of suppression or enhancement.

Figure 8 shows nuclear modification factor, R_{AA} of ϕ and ω with other hadrons; proton[12], kaon[12] π^0 [13] and η [14]. Protons are enhanced at $p_T > 1.5$ GeV/c and kaon is less suppressed than π^0 and η . π^0 and η mesons follow the same suppression pattern while ϕ mesons appear to be less suppressed in the range of $2.45 < p_T < 4.5$ GeV/c and become similar to π^0 and η at

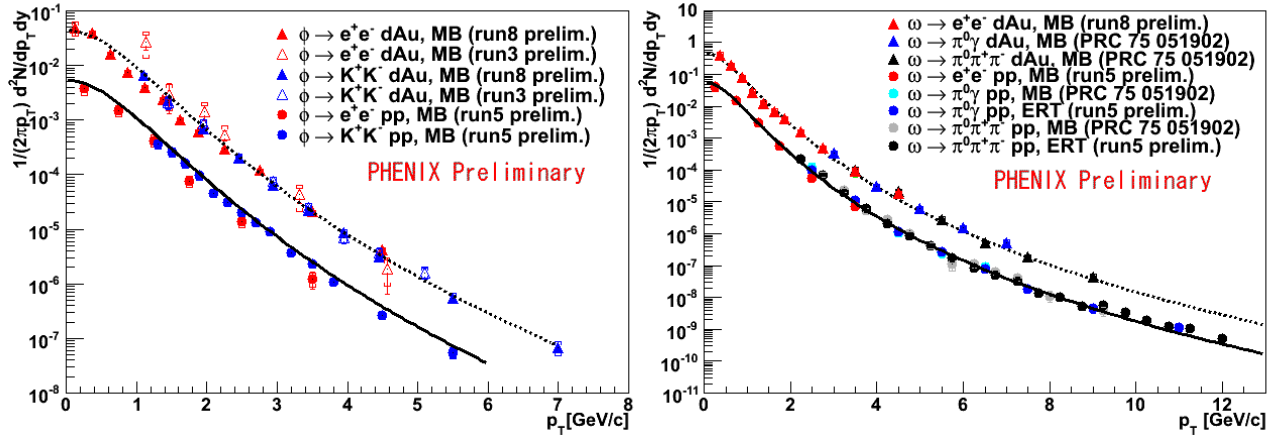


Figure 5. Invariant transverse momentum spectra of ϕ (left) and ω (right) in p+p and d+Au. The solid line represents a Levy fit[15] to both hadron and electron channels in p+p collisions. The dashed line is the same fit scaled by the expected N_{coll} for the case of d+Au.

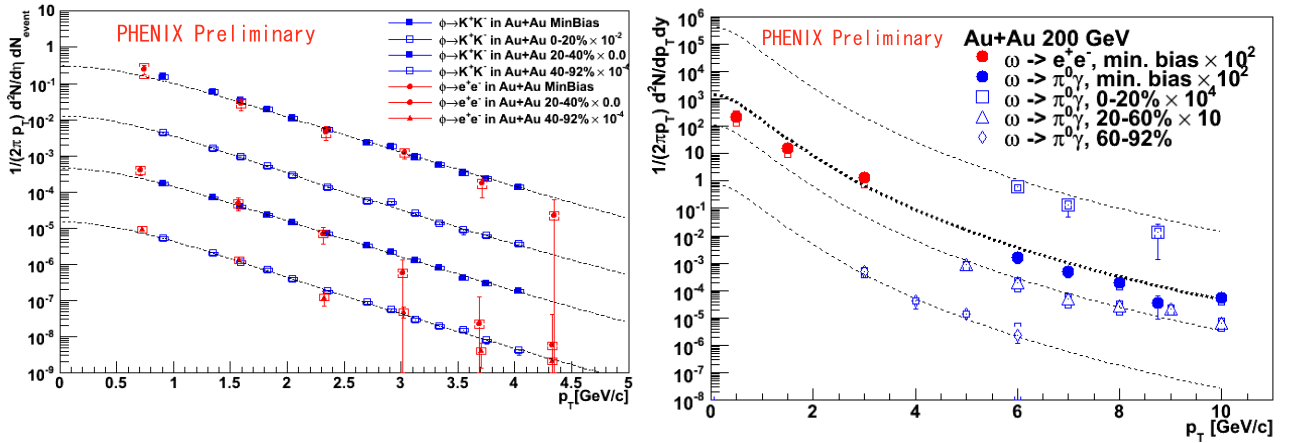


Figure 6. Invariant transverse momentum spectra of ϕ (left) and ω (right) in Au+Au. The dashed lines are a Levy fit to p+p results scaled by the expected N_{coll} for corresponding centralities in Au+Au.

high p_T , so do ω mesons within errors. The different behavior of kaon and ϕ suppression pattern ($p_T < 4.5$ GeV/c) is under discussion. Since there is no overlap p_T region between them, the results cannot attribute to an onset of flavor.

ω analysis is going to include more statistics in Au+Au to reduce statistical errors and also add Cu+Cu analysis for the systematic study to affirm that all hadron production in high p_T follows the picture of the parton fragmentation mechanism. On the other hand, comparison study of Au+Au and Cu+Cu data for ϕ was performed and it shows no significant difference (See the Figure 9).

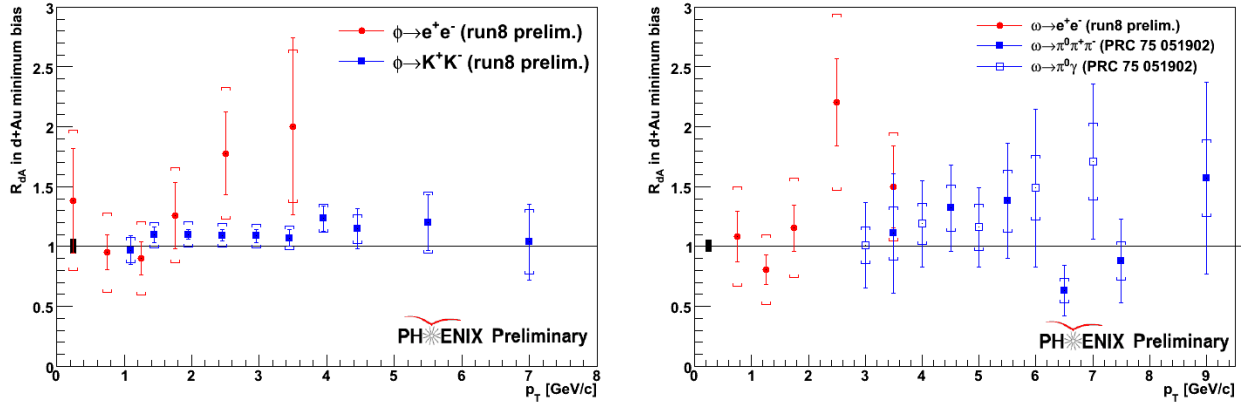


Figure 7. Nuclear modification factor, R_{dAu} , versus transverse momentum in minimum bias d+Au. Data for ϕ shown with both $\phi \rightarrow e^+e^-$ and $\phi \rightarrow K^+K^-$ (left) and ω with both $\omega \rightarrow e^+e^-$ and $\omega \rightarrow \pi^0\gamma$ [11].

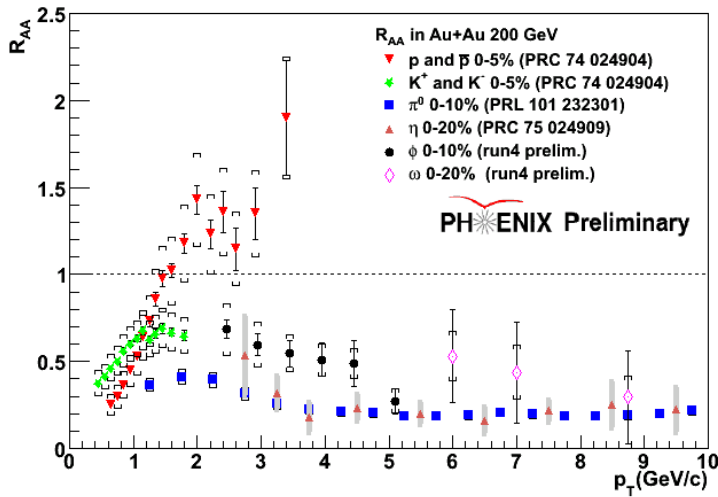


Figure 8. Nuclear modification factor R_{AA} as a function of p_T for ϕ and ω with π^0 [13], η [14], $(K^+ + K^-)/2$ and $(p + \bar{p})/2$ [12] (explanation of each suppression pattern is in text).

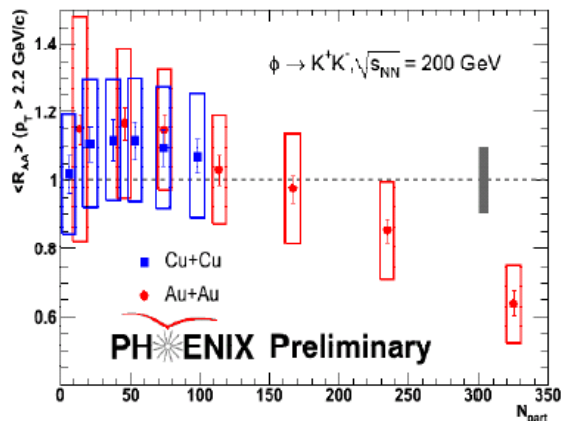


Figure 9. ϕ mesons's integrated R_{AA} for Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV for similar number of participating nucleons $<N_{part}> [8]$.

5. Summary

The PHENIX has measured the production of ϕ and ω mesons via both leptonic and hadronic decay modes in p+p, d+Au, Cu+Cu and Au+Au at C.M.S. collision energy per nucleon pair of 200 GeV. The results show a good agreement for invariant yield spectra in different decay modes in p+p and in d+Au respectively. The modification factor, R_{AA} suggests suppression of ϕ/ω at high p_T . More statistics will be available in Au+Au data which is taken in 2007-2008 and 2009-2010 with a HBD detector which has a capability to reject the π^0 dalitz background, thus able to reduce the uncertainties.

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