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# Low-Mass Vector Mesons and Continuum at RHIC-PHENIX

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**Abstract.** The PHENIX experiment at RHIC is uniquely suitable for systematic measurements of low-mass vector mesons and continuum, and has addressed multifold physics in the mass region. Solid and systematic baselines have been established in proton-proton ($p$+$p$) and deuteron-gold ($d$+Au) collisions for measurements of $\omega$ and $\phi$ mesons via their multiple decay modes and of the electron-positron continuum. Technical challenges in gold-gold (Au+Au) collisions have also been identified, attacked and well overcome in electron, photon and hadron measurements. The latest results from $p$+$p$ collision data taken in 2005, $d$+Au in 2003, and Au+Au in 2004, all at the center-of-mass energy of nucleon-nucleon collision ($\sqrt{s_{NN}}$) of 200 GeV, are presented and discussed.

*Keywords:* quark gluon plasma, chiral symmetry restoration, dielectron, vector meson, continuum
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## 1. Introduction

The PHENIX experiment at RHIC is uniquely suitable for systematic measurements of low-mass vector mesons and continuum, where a number of interesting physics topics are accessible. For example, low-mass vector mesons especially in low transverse momentum region are beloved probes of partial chiral symmetry restoration [1], via possible modification of their mass spectrum shapes and/or branching ratios. The same mesons in high transverse momentum region are in turn a good tool for quark tomography to probe flavor and/or spin dependences of quark energy loss. The electron-positron continuum is known to exhibit an enhancement, especially in low transverse momentum region, in heavy ion collisions over the elementary production in proton-proton collisions, which has been long observed [2] though yet to be understood. Finally, the low-mass continuum in high transverse momentum region is recently regarded as a powerful tool to access direct virtual photons [3].

In this article, the latest results from the PHENIX experiment are presented and discussed on the first three topics of the four mentioned above. The last one, a virtual photon measurement, is described in a separate article in these proceedings [4].

## 2. Experimental Approaches

### *2.1. The PHENIX experiment*

The fundamental strategy of the PHENIX experiment is systematic studies of rare probes, by utilizing multiple probes such as photons, leptons and hadrons, with a special emphasis on transparent ones. For details of PHENIX, see, *e.g.*, [5].

### *2.2. Data sets*

In this article, results are presented based on proton-proton ($p$+$p$) collision data taken in 2005, deuteron-gold ($d$+Au) in 2003, and gold-gold (Au+Au) in 2004, all at the center-of-mass energy of nucleon-nucleon collision ($\sqrt{s_{NN}}$) of 200 GeV. It should be noted that PHENIX has collected higher statistics data for all of those collision systems in recent runs, which are still under careful analysis.

### *2.3. Technical highlights*

One of the key measurements in low-mass region is electron-positron pairs, or dielectrons in short. PHENIX makes the best use of its precise tracking and electron identification capabilities for the technically challenging measurement. A background component from photon conversion at the beam pipe and other materials is identified and rejected based on the orientation of opening of the pair. Non-correlated pairs of electron and positron, primarily from Dalitz decays of $\pi^0$ and $\eta$, are statistically evaluated and subtracted, as well as less significant contributions of correlated pairs such as cross pairs from processes emitting two or more electron-positron pairs and a jet component. For technical details of dielectron measurement and analysis in PHENIX, see [3, 6, 7].

In measurement of decay channels into multiple particles, identification of daughter particles often limits the acceptance, efficiency and momentum range of the measurement of the parent. In $\phi \to K^+K^-$ mode, no kaon and single kaon identification methods are introduced in addition to the traditional two kaon identification method, to extend the momentum region of the measurement considerably to the high side. In low momentum region, on the other hand, particle identification of the daughter particles improves the signal-to-background ratio. These methods are applied separately, compared in overlapping regions for consistency, and merged to cover wide kinematic ranges.

## 3. Search for Mass Modification of Low-Mass Vector Mesons

### *3.1. Mass spectra of $\omega$ and $\phi$ mesons*

Direct measurement of mass spectra is the most naive method to look at the possible mass modification of low-mass vector mesons in hot matter. The change is expected to be more prominent in low transverse momentum region as the lifetimes of those particles are in the same order as that of the hot partonic phase.

In the baseline measurements in $p$+$p$ and $d$+Au collisions, clear peaks of $\omega$ and $\phi$ are observed in multiple decay modes, such as $\omega \to e^+e^-$, $\omega \to \pi^0\gamma$, $\omega \to \pi^0\pi^+\pi^-$, $\phi \to e^+e^-$, and $\phi \to K^+K^-$, with good mass resolutions except in the radiative decay mode of $\omega$. As an example, Fig.1 shows an invariant mass spectrum of dielectrons in $p$+$p$ collisions.

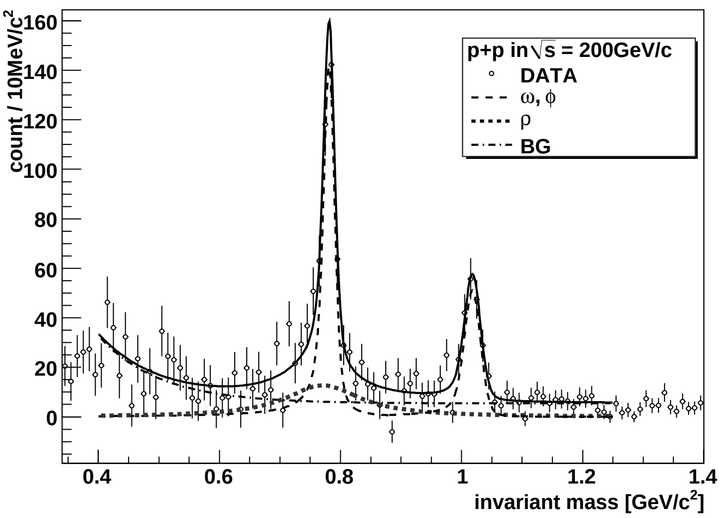


**Fig. 1.** An invariant mass spectrum of dielectrons in $p$+$p$ collisions after subtraction of combinatorial background. The lines show $\omega$ and $\phi$ peaks including their radiative tails, a $\rho$ contribution, and a background component.

In Au+Au collisions, however, the statistics in the 2004 run is only marginal in the featured dielectron mode to discuss mass modification, as shown in Fig.2. The mass line shape analysis is hoped to be accomplished in the later runs with higher statistics.

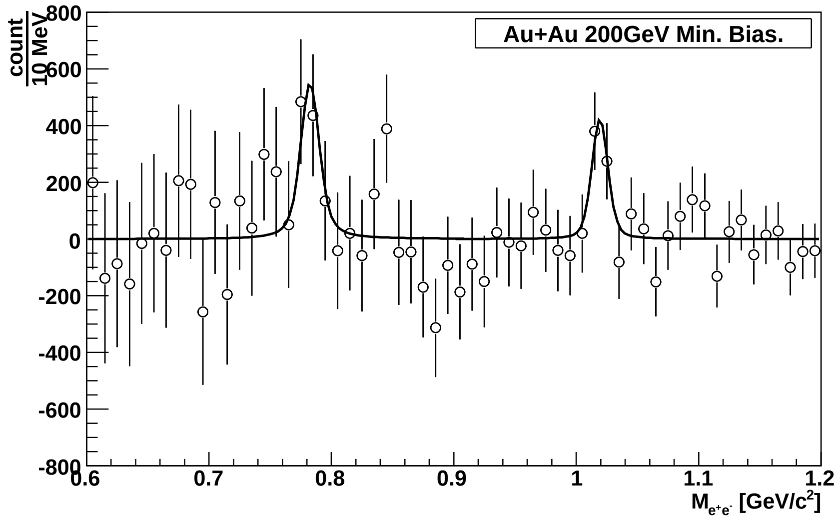


**Fig. 2.** An invariant mass spectrum of dielectrons in minimum-bias Au+Au collisions after background subtraction.

### *3.2. Branching ratio of $\phi$ meson*

Another way to probe the possible mass shift is the branching ratio of $\phi$ meson, as a suppression may occur in the $K^+K^-$ mode compared to $e^+e^-$ if the mass of $\phi$ shifts downward as predicted by theories [1]. The decay mode can be even prohibited in an extreme case that a $\phi$ becomes lighter than two charged kaons. The change is again expected to be more prominent in low transverse momentum region, if it exists.

In the baseline measurements in $p$+$p$ and $d$+Au collisions, the transverse momentum spectra of $\phi$ agree well within the errors for the two decay modes, as shown in Fig.3 (top).

In Au+Au collisions, a long awaited result of dielectron decay mode of $\phi$ has come very close to final. No significant signature of mass modification is observed beyond the errors, as shown in Fig.3 (bottom). 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.

## 4. Quark Tomography

It has been an established understanding that an energy loss of hard quarks is implied in the partonic level. Measurement of nuclear modification of particle yields

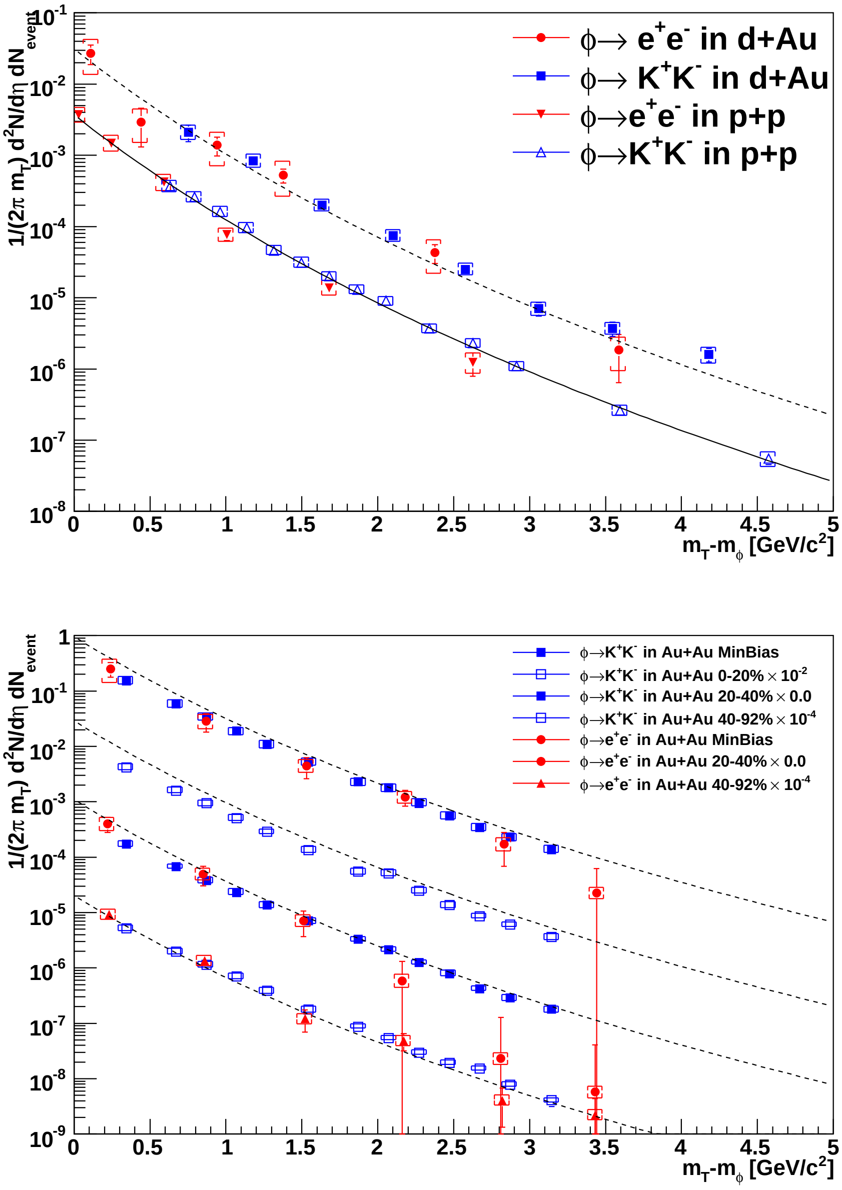


**Fig. 3.** Invariant transverse momentum spectra of $\phi$ meson in $p$+$p$ and $d$+Au collisions (top) and in minimum-bias Au+Au (bottom).

becomes an even cleaner signal of quark energy loss in higher transverse momentum region, as other mechanisms get less significant. In terms of particle identification at high momentum, mesons decaying into multiple photons have an advantage. In addition to well measured $\pi^0$ and $\eta$, further extending systematic measurements are awaited for tomographic studies, such as a dependence on quark flavors and possible difference between pseudo-scalar and vector mesons. In these two regards, photon decay modes of (vector) mesons have been highly motivated.

Recent progresses in analysis have successfully extended the transverse momentum reaches in the high sides both for $\omega$ (in $\pi^0\gamma$ mode) and $\phi$ (in $K^+K^-$ mode), as partly described in Section 2.3. It has been found that the nuclear modification of $\omega$ and $\phi$ may be showing interesting behaviors, as shown in Fig.4, which could be an onset of a dependence of quark energy loss on flavor and/or spin. $K_s^0$ is another interesting probe in that regard, whose measurement in high transverse momentum region is in progress via its $\pi^0\pi^0$ decay mode.

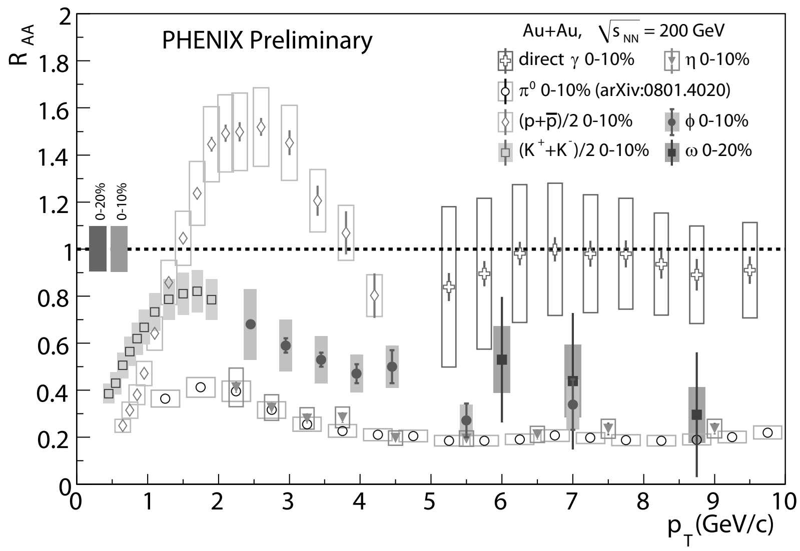


**Fig. 4.** Nuclear modification factors of various particles in central Au+Au collisions.

## 5. Low-Mass Continuum Enhancement

Enhancement of low-mass dilepton continuum has been long known since the SPS era [2], but has not been uniquely understood as there are several explanations including melting of $\rho$ meson, broadening, and existence of thermal virtual photon. PHENIX has an advantage over other experiments that the continuum can be measured with the peak structures well separated due to its high resolution.

In $p$+$p$ collisions, with the signal-to-background ratio as high as $\sim 1$, the result agrees with the contributions from hadron decays and heavy quarks, as shown in Fig.5 [6]. It in facts provides an information on the production cross section of charm quarks, which is consistent with the result from the independent single electron measurement by PHENIX [8].

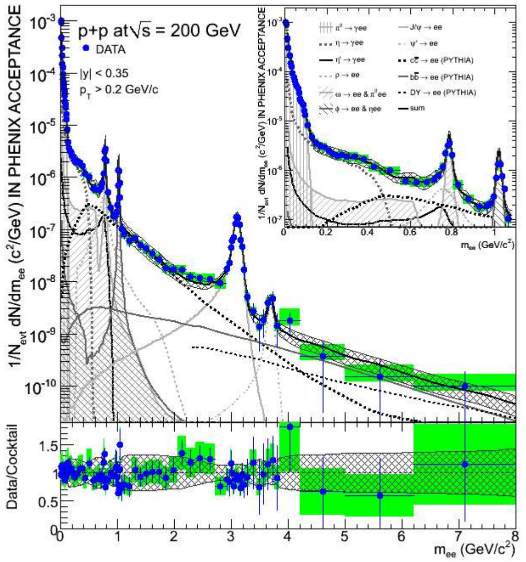


**Fig. 5.** An invariant mass spectrum of dielectrons in $p$+$p$ collisions after background subtraction [6].

In minimum-bias Au+Au collisions, the signal-to-background ratio drops drastically to $\sim 1/200$ in the low-mass region, as shown in Fig.6. The result is, however, cross checked with an independent data set with an additional photon converter installed around the beam pipe, to find a good agreement. The continuum is enhanced by a factor of $3.4 \pm 0.2(stat.) \pm 1.3(sys.) \pm 0.7(model)$ in the mass region from 150 to 750 MeV, below $\omega$ and $\rho$, in minimum-bias Au+Au collisions over $p$+$p$ [7]. The excess is concentrated in low transverse momentum region and increases with the collision centrality faster than the number of participant nucleons. The enhancement is not described by any existing theoretical model, in contrary to the SPS data.

## 6. Summary, Concluding Remarks and Outlook

The PHENIX experiment at RHIC has addressed multifold physics in low-mass region making the best use of its precise tracking and particle identification capabilities. Solid and systematic baselines have been established in $p$+$p$ and $d$+Au collisions for measurements of low-mass vector mesons via multiple decay modes

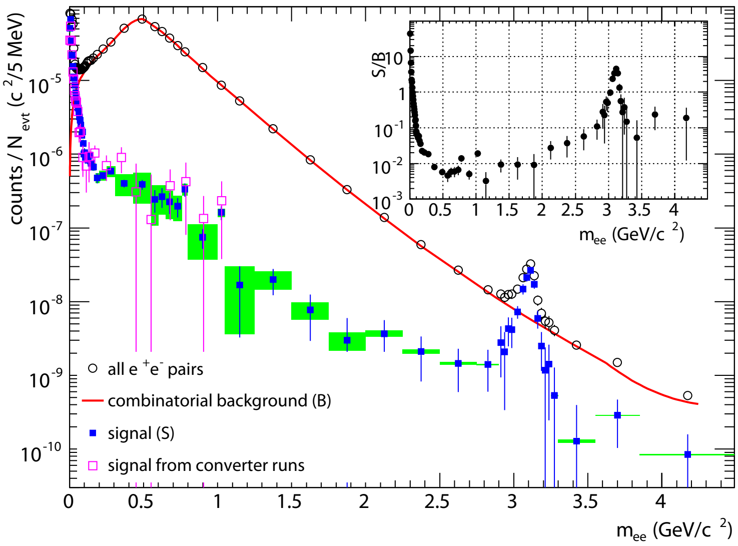


**Fig. 6.** Invariant mass spectra of dielectrons in minimum-bias Au+Au collisions [7].

and of the dielectron continuum. Technical challenges in Au+Au collisions have also been identified, attacked and well overcome in electron, photon and hadron measurements. The results from data taken in 2003-2005 are finalized or close to, with which publications are in preparation. Further systematic studies are laid out and partially underway, including the hadron blind detector awaiting for the next Au+Au run.

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