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Low mass dilepton production at RHIC energies

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Abstract. Recent results on low mass dilepton measurements from the PHENIX experiment are reported. Invariant mass spectra of $\phi \to e^+e^-$ are measured for the first time in Au-Au collisions at $\sqrt{s_{NN}} = 200\,\text{GeV}$ in Run2. In d-Au collisions, the yields and M_T slopes of both $\phi \to e^+e^-$ and $\phi \to K^+K^-$ are measured. Both results are consistent with each other within errors. In the future, a Hadron Blind Detector will be installed in PHENIX which will enhance our capabilities of rejecting external photon conversions and Dalitz pairs, that will result in a significant reduction of the large combinatorial background.

1 Introduction

Since the first Au+Au collisions were observed at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), many new phenomena related to hot and dense nuclear matter have been discovered. In particular, the PHENIX experiment produced many new results on a wide range of physics subjects, including charged and neutral hadron production, single electron production, event isotropy, and many other topics [1].

In spite of these fruitful results, in the first three years of RHIC operation, there are still remaining questions to be answered to further characterize the state of matter formed at RHIC. In particular, direct information of deconfinement of quarks and gluons and chiral properties of the dense matter produced has not been obtained, and should be provided.

Electromagnetic probes are created in the medium, and emerge from the matter without strong final state interaction. Thus, they carry direct information about conditions and properties of the medium. The dilepton continuum from thermal radiation and lepton decays of vector mesons are the ones considered as electro-magnetic probes. CERES measured low mass lepton pairs at SPS energies and showed an excess in their dielectron spectrum with respect to the expected hadronic decays [2]. At RHIC energies, so far, only hadron decays of vector mesons have been measured [3–5]. A measurement of lepton pairs in the low mass region at RHIC energies is needed to look for new sources of dileptons, beyond the hadron decays, and to see if the dilepton decays of the vector mesons differ from their hadronic decays, which would give information on the properties of the produced medium.

Of many vector mesons, $\phi(1020)$ is an interesting meson because the restoration of approximate chiral symmetry at high temperature may modify its mass and width [6]. These modifications can be shown in the line shape of the $\phi \to e^+e^-$ peak. Also, the branching fraction of $\phi \to K^+K^-$ and $\phi \to e^+e^-$ could be changed when the ϕ decays in medium [7]. Note that the ϕ lifetime $\tau \approx 44$ fm/c is longer than the expected lifetime of the coupled collision system, and thus only a fraction of produced ϕs may decay in the hot fireball. It has also been hypothesized that final state interactions of kaons from ϕ decay may lower the apparent measured branching fraction in the kaon channel [8]. In addition, the measurement of p_T slopes of ϕs decaying into lepton pairs and hadron pairs will illuminate different stages of collision. When the final state interaction is taken into account, only hadrons generated in the last stage can be observed.

Line shapes, yields, and p_T slopes of $\phi \to K^+K^-$ and $\phi \to e^+e^-$ should be measured in p-p, d-Au and Au-Au collisions. Measurements in p-p and d-Au collisions provide baseline information without any "hot" nuclear matter effects. In this paper, the results on $\phi \to e^+e^-$ in Au-Au collisions in Run2 and d-Au collisions in Run3 at $\sqrt{s_{NN}}$ =200 GeV are reported. Results on $\phi \to K^+K^-$ in Au-Au collisions are quoted from [5].

2 PHENIX experiment

The PHENIX experiment is specifically designed to measure low-mass lepton pairs, and the detector upgrade described in a later section will greatly enhance its capability. The current PHENIX detector consists of two central spectrometer arms for measuring electrons. Further details of the detector design and performance are given in [9].

Each central arm covers pseudo-rapidity of $|\eta| < 0.35$, transverse momentum of $p_T > 0.2$ GeV/c, and azimuthal angle of $\delta\phi = \pi/2$. They include, from the inner radius outward, a Multiplicity and Vertex Detector (MVD), Drift Chambers (DC), Pixel Pad Chambers (PC), Ring Imaging Čerenkov Counter (RICH), Time Expansion Chamber (TEC), Time-of-Flight Scintillator Wall (TOF), and two types of Electromagnetic Calorimeters (EMC). This combination of detectors is necessary for the clean identification of electrons over a broad range of transverse momentum. The Au-Au, d-Au, and p-p collisions are detected

* Deceased
† Spokesperson

with minimum bias triggers based on a set of zero degree calorimeters (ZDC) and beam-beam counters (BBC).

From the year 2000 to 2003, we successfully operated the detector system and collected a large amount of data in p-p, d-Au, and Au-Au collisions. During the fourth running period (Run 4), RHIC delivered a luminosity of approximately 1400 μb^{-1} to the PHENIX intersection region within a vertex z range ($|z| < 45$ cm). PHENIX successfully recorded on the order of $1.5 \cdot 10^9$ "minimum bias" Au-Au events at $\sqrt{s_{NN}} = 200$ GeV after a vertex selection of $|z| < 30$ cm.

3 ϕ meson production in Au-Au

PHENIX has the unique capability of reconstructing the ϕ meson in both the K^+K^- and e^+e^- channels. Especially, PHENIX has an excellent electron identification capability that is necessary to separate electrons from the much more abundant charged pions. The RICH provides a threshold selection for electrons and the EMC confirms the matching of the tracked momentum and electromagnetic energy (E/p). Since electrons deposit all of their energy in the EMC, E/p for electrons should be approximately unity. Figure 1 shows the $(E-p)/p/\sigma$ distribution. Here the σ stands for the standard deviation of $(E-p)/p$. A background of less than 10 %, caused by accidental association of tracks with RICH hits, still remains.

Figure 2 shows the e^+e^- invariant mass distribution from Run2 data after mixed event background subtraction. There is an excess of counts around the ϕ mass with a signal strength of $101 \pm 47(\mathrm{stat})^{+56}_{-20}(\mathrm{sys})$ and a signal to background ratio of 1/20. Within relatively large errors, the mass peak and width values agree with the values from the Particle Data Group.

We accumulated twenty times larger statistics in Run 4. Also, PHENIX in Run 4 had twice larger pair acceptance and less background compared with Run 2 due to the absence of the multiplicity detector. Thus, we can expect a significant improvement in the electron pair analysis in Run 4. Analysis of ϕ mesons and thermal radiation in Au-Au collisions is underway using Run4 data.

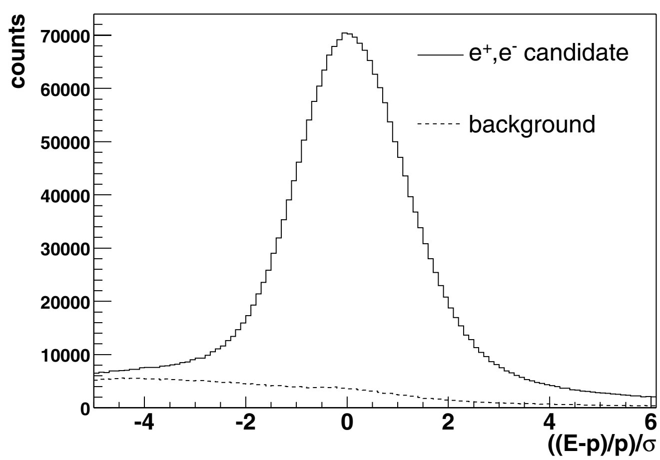

Fig. 1. $(E-p)/p/\sigma$ distribution. A background of less than 10 %, caused by accidental association of tracks with RICH hits, still remains

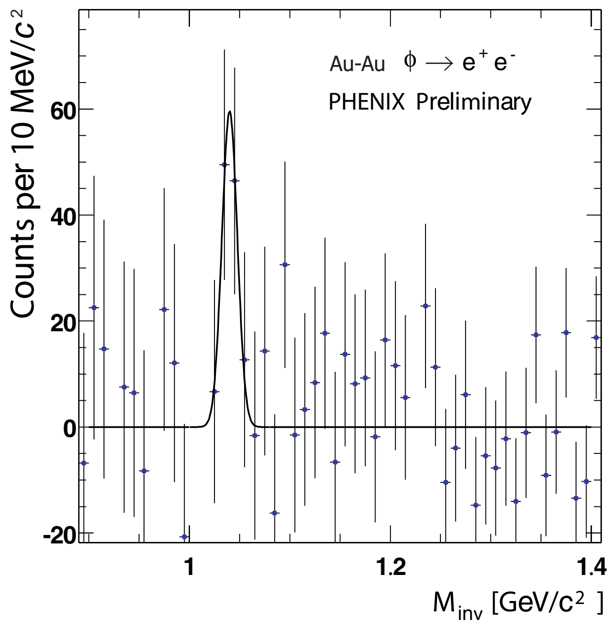

Fig. 2. e^+e^- invariant mass distribution after mixed event subtraction for minimum bias (0–90 % central) Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV in Run 2

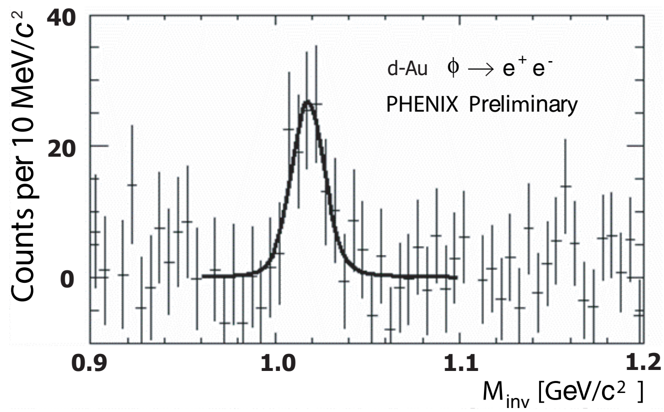

Fig. 3. Background subtracted e^+e^- invariant mass spectrum with a fit as described in the text

4 ϕ meson production in d-Au

About 31 million single-electron triggered d-Au events were accumulated. The trigger required the matching of hits in the RICH and EMC. The energy threshold of the EMC trigger was set to 600 MeV. Figure 3 shows the e^+e^- invariant mass distribution in d-Au collisions after mixed event background subtraction.

The background subtracted signal was fit with a relativistic Breit-Wigner function convoluted with a Gaussian to obtain the raw yield. The yield was divided into three m_{T} bins, and corrected for acceptance and efficiencies. The total invariant yield ($\mathrm{d}N/\mathrm{d}y$) and inverse slope

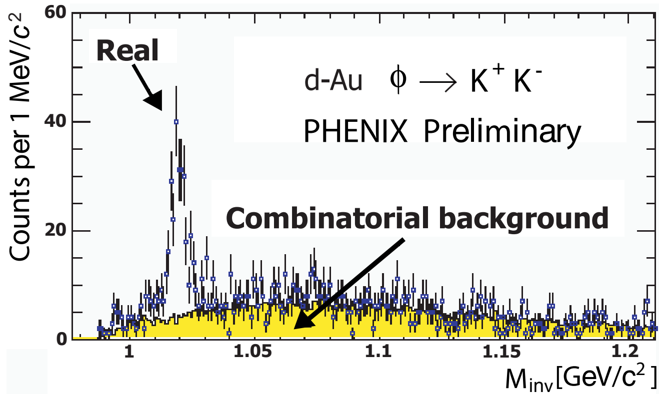

Fig. 4. K^+K^- invariant mass spectrum with the background superposed

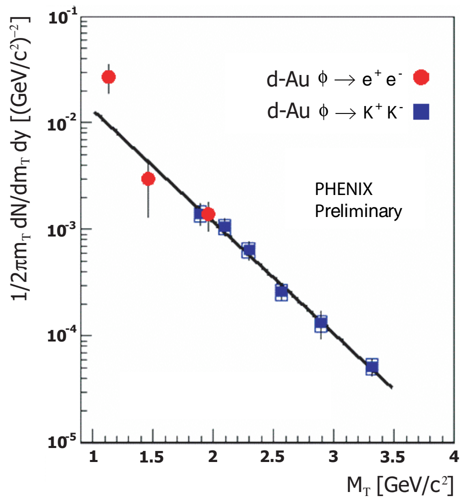

Fig. 5. m_T spectrum for minimum bias events from both the e^+e^- and K^+K^- channels. A fit is made to all the data points

of m_T spectra were obtained by fitting the m_T spectra. Major contributors to the systematic error on dN/dy are the normalization of the background, its effect on the inverse slope, and the run-by-run variations of the electron trigger efficiency.

About 62 million minimum bias d-Au events were used for the K^+K^- analysis. Figure 4 shows the K^+K^- invariant mass distribution in d-Au collisions with the background superposed. Kaons were identified in the TOF which covers $\Delta\phi \approx 40°$. Because of the limited coverage of the TOF, the kaon channel analysis accepts ϕ's with higher momentum compared to the electron channel analysis. The invariant mass spectrum was generated by combining unlike sign pairs of kaons. The background shape was obtained by an event mixing method. The procedure of computing the total invariant yield and inverse slope of the m_T spectra is the same as the one for the e^+e^- channel. Because of the good signal to background in the K^+K^- channel, systematic errors are considerably smaller than in the electron channel. The systematic errors are dominated by the range in m_T over which the fit was done, the run-by-run changes in efficiency, and the corrections due to the fiducial cuts.

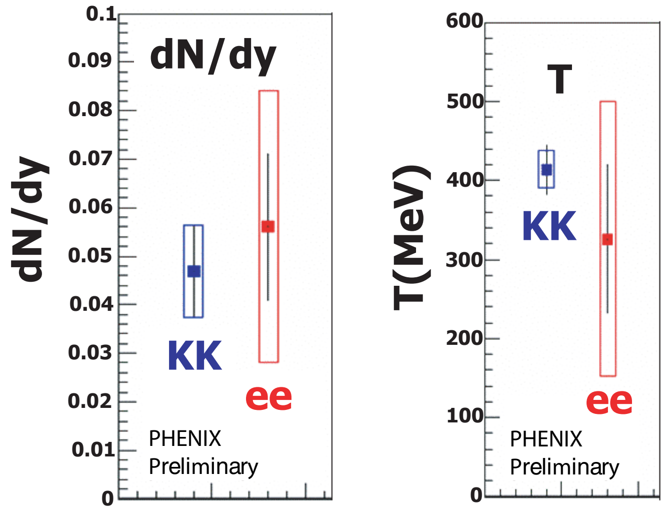

Fig. 6. Comparison of the yields (left) and inverse slopes (right) of the ϕ, as measured through the two decay channels

Results for e^+e^- and K^+K^- data are shown in Fig. 5 and Fig. 6. The two data samples are consistent in both the total invariant yield and inverse slope. Because of the small fraction of ϕ's that decay inside the relevant volume, the effect from chiral symmetry restoration, particularly in d-Au collisions, is expected to be small.

5 Hadron Blind Detector

There are several measurements which are beyond the scope of the present PHENIX detector. To extend the capability of the measurement of lepton pairs, several upgrade projects of the detector are currently underway.

The difficulty of the measurement of low mass electron pairs comes from the large combinatorial background, which is mainly due to π^0 Dalitz decays and external conversion of photons. Thus, for this measurement, a Dalitz rejector with a large rejection power covering a large solid angle is needed.

The proposed Dalitz rejector is composed of two essential elements; zero magnetic field, and improved electron identification. Electron-positron pairs from Dalitz decays and gamma conversions have a very small angle. Thus, these pairs produce very close hits in the electron identification detector under zero field conditions. The zero magnetic field is realized by canceling the magnetic field produced by the outer coils of the PHENIX central magnet with the reverse magnetic field produced by a set of inner coils.

To realize electron identification near the vertex region, a hadron blind detector (HBD), which is a threshold-type Čerenkov counter using CF_4 as a radiator gas [10], is proposed. The conceptual design of the HBD is shown in Fig. 7.

The detector consists of a 50 cm long radiator, directly coupled in a windowless configuration to a triple GEM

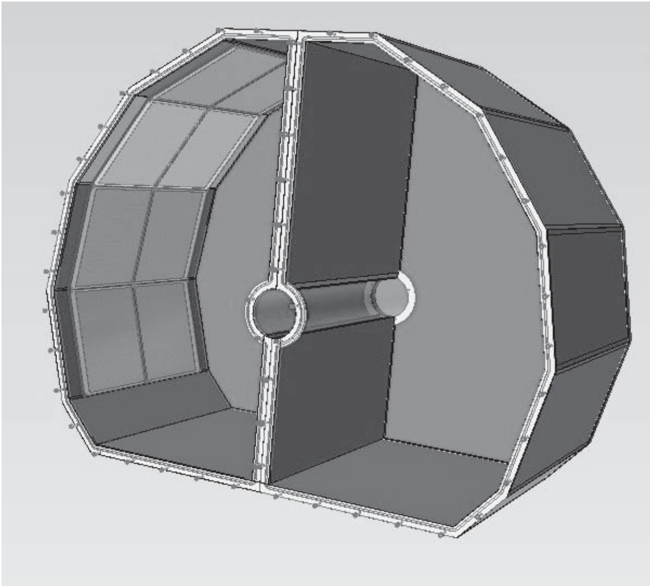

Fig. 7. Conceptual design of hadron blind detector

detector which has CsI photocathode evaporated on the top face of the first GEM foil, and pad readout at the bottom of the GEM stack [11]. Eight modules of GEM stacks are shown in Fig. 7.

The R&D phase to demonstrate the validity of the HBD concept is nearly complete. A test of a prototype detector was performed at KEK using electron and charged π meson beams. The preliminary result of the test showed that charged π mesons produce only a very small number of photoelectrons ($\sim$3–5). A subsequent test will be done at BNL to evaluate the total performance of the prototype. Construction of the final detector will start soon and the detector is expected to be installed in PHENIX in 2006.

6 Summary

Invariant mass spectra of $\phi \rightarrow e^+e^-$ were measured for the first time in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV in Run 2. Significantly improved statistics of Au-Au collisions are achieved in Run 4. Results from Run 4 data will appear soon.

In d-Au collisions, the yields and m_{T} slopes of both $\phi \rightarrow e^+e^-$ and $\phi \rightarrow K^+K^-$ are measured. Both results are consistent with each other within errors. In the future, a Hadron Blind Detector will be installed in PHENIX that will enhance our capabilities of rejecting external photon conversion and Dalitz pairs, and will result in a significant reduction of the large combinatorial background. This will open up the possibility of studying chiral symmetry restoration as well as thermal di-electrons.

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