論文の内容の要旨

論文題目　Measurements of di-electron production in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV

（核子対あたり重心系エネルギー200GeVでの金・金衝突における電子対測定）

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High-energy heavy ion collisions provide the unique opportunity to study strongly interacting matter at extreme conditions of temperature and/or density in the laboratory. Immediately after the collision, a huge amount of energy is released in a tiny volume and free partons are produced. Eventually the formed partonic matter expands and the gas of hadrons is formed. The purpose of this research is to measure the properties of the partonic matter and the hadron gas using di-electron channel.

Di-electron measurement is a powerful tool to diagnose the strongly interacting matter formed in high-energy heavy ion collisions. Di-electrons are not subject to the strong interaction. Therefore, they are not distorted by final state interactions and carry information about the properties of the matter at the time of their production.

The hot/dense matter formed in heavy-ion collisions affects the mass spectra in various ways. The shape of the low mass region (Below the ρ mass) is expected to be modified due to the in-medium modification of low mass vector mesons, in particular ρ meson. Two main models with such in-medium modifications are a dropping mass scenario and a broadening mass scenario. In addition, theory predicts that the intermediate mass region (above the ϕ mass and below the J/ψ mass) is the most appropriate window to observe the thermal radiation from the partonic medium.

To search for the possible spectral modifications, the extracted signal in the data analysis is compared to the e^+e^- contribution from known hadron decays, which we call “cocktail”. The cocktail consists of several ingredients. The π^0, η, η' Dalitz decays, di-electron decays of the vector mesons (ρ, ω, ϕ, J/ψ) and the correlated pairs from semi-leptonic decays of heavy flavor (charm and bottom) mesons.

Di-electron measurements in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV are already performed by PHENIX(Run-4) and recently by STAR. (STAR results are still preliminary.) PHENIX observed a large enhancement of the e^+e^- yield compared to the cocktail in the low mass low p_T region. They reported an enhancement by a factor of 4.7±0.4(stat)±1.5(syst)±0.9(model) in the mass window 0.15-0.75 GeV/c^2 and without p_T selection for minimum bias events. None of the models with in-medium modification of the ρ meson spectrum manages to reproduce the enhancement and its origin is still not understood. In contrast, STAR did not observe such a strong enhancement and their results are compatible with the ρ broadening scenario. Therefore, it is crucial to perform an additional measurement and settle the inconsistency between the two experimental results. PHENIX(Run-4) and STAR also measured the dielectrons spectrum in the intermediate mass region. Their results are both consistent with the open charm contribution scaled by the number of binary collisions (N_{coll}) within the experimental uncertainties and the QGP radiation is not confirmed. Rather, the STAR results show a hint of suppressed yields from the N_{coll} scaling. An additional measurement can provide further insight into the spectral modifications in the intermediate mass region.

We performed a di-electron measurement at mid-rapidity ($|y|<0.35$) using the upgraded PHENIX detector with Hadron Blind Detector (HBD) in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV in 2010 (RHIC Run-10). The HBD is a Cherenkov detector consisting of a 50 cm long radiator operated with pure CF_4 and directly coupled to a triple Gas Electron Multiplier (GEM) photon detection element. The HBD aims at rejecting electrons coming from π^0 Dalitz decays and γ conversions, which are major background sources in di-electron analysis. This is achieved by exploiting the fact that the opening angle of electron pairs from these sources is very small compared to the opening angle of other sources like the light vector mesons. As a consequence, the electrons originating from those background sources produce double signal amplitude compared to that of a single electron in HBD. Since HBD is a new detector, its calibration scheme has been developed and described in this manuscript.

The major difficulty in the di-electron analysis is in the background subtraction. Ideally, we would like to analyze only the “physical” pairs. The “physical” pairs are defined as e^+e^- pairs from the same parent particle, e.g. an electron and a positron from ϕ meson decay, or e^+e^- pairs from semi-leptonic decays of heavy flavor mesons, which are correlated through flavor conservation. However, the sources of electrons and positrons are not known in a real event. Therefore, all electrons and positrons in the same event are combined to form “foreground” pairs. To extract the mass spectrum of the physical pairs, the contributions from the background pairs need to be subtracted statistically.

The background pairs consist of the following types: combinatorial pairs, cross pairs, jet pairs and electron-hadron pairs. The combinatorial pairs are random combinations of electrons and positrons from different parent particles and are just the result of combining all electrons and positrons in an event. The cross pairs occur when there are two e^+e^- pairs in the final state of a meson, e.g. $\pi^0 \rightarrow e^+e^-\gamma \rightarrow e^+e^-e^+e^-$. The combination of an electron directly from π^0 and a positron from γ do not have the same parent particle but they are correlated through the same grand parent particle. Two electrons generated in the same jet or in the back-to-back jets produce the jet pairs. The electron-hadron pairs result from the detector correlations. The background subtraction procedure is verified using the like-sign, e^+e^+ and e^-e^-, mass spectra, which have contributions from only “unphysical” pairs.

Figure 1 shows the minimum bias spectrum obtained in this analysis compared to the cocktail of hadronic sources. The difference between the data and the cocktail around J/ψ is consistent with the measured “J/ψ suppression” in PHENIX(Run-4) and STAR. Figure 2 show the ratio data/cocktail versus the number of participating nucleons (N_{part}) for the integrated yield in the low mass region, m = 0.15 - 0.75 GeV/c^2 (left panel) and in the intermediate mass region, m = 1.2-2.8 GeV/c^2 (right panel).

The data is consistent with the cocktail in the low mass region. However, the inclusive data/cocktail ratio in this analysis and in PHENIX(Run-4) are not directly comparable due to the different single track p_T cut; p_T>0.3 GeV/c in this analysis and p_T > 0.2 GeV/c in Run-4 analysis. The stronger single p_T cut results in the smaller acceptance in small mass and pair p_T region. Therefore, the acceptance corrected p_T spectrum in the low mass region for minimum bias events is studied. The p_T spectrum in the region 0.3 < m < 0.5 GeV/c^2 is shown in Fig. 3. At high p_T, p_T > 1.5 GeV/c, an excess from the cocktail is observed. The excess is consistent with the contribution from the virtual photon associated with direct photon production measured by PHENIX(Run-4). At low p_T, the measured yield is consistent with the cocktail. In the region, PHENIX(Run-4) observed a large enhancement beyond the cocktail; however, the enhancement is not confirmed in this research. Since the experimental uncertainties are large, the possibility to have in-medium modification of ρ meson predicted by several models are not eliminated.

In the intermediate mass region, the obtained yields are consistent with N_{coll} scaling of the open charm contribution as observed PHENIX and STAR before. However, within the experimental uncertainties, the possibility of having the QGP radiation in the mass region is not ruled out.

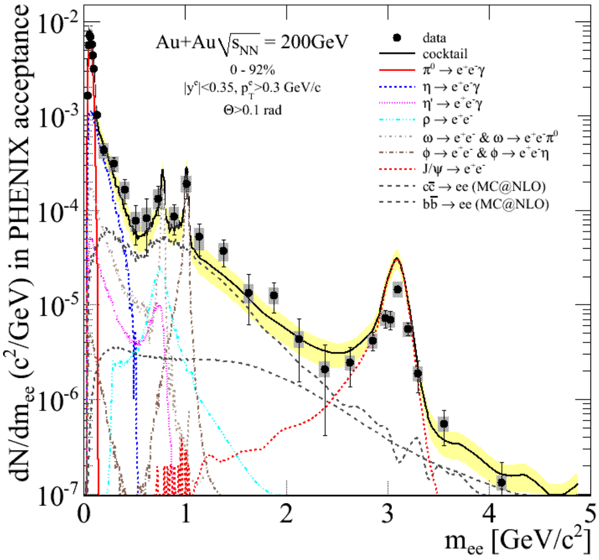

Figure 1: Invariant mass spectra of e^+e^- pairs in the PHENIX acceptance for minimum bias events. The experimental results are compared to the expected yield from the cocktail of light hadron decays, correlated heavy flavor decays and J/ψ decays. Statistical and systematic errors both on the data and the cocktail are included.

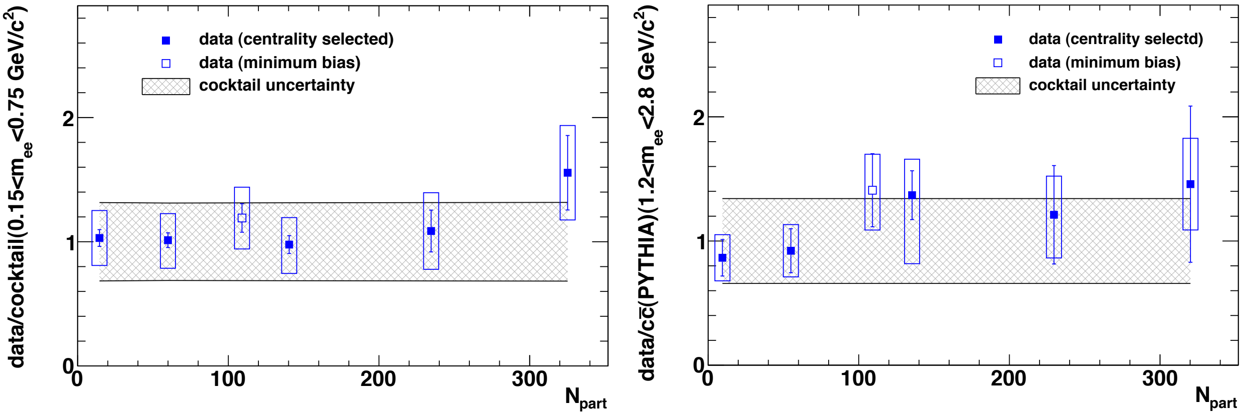

Figure 2: Data/cocktail ratio in the mass region 0.15-0.75 GeV/c^2(left) and 1.2-2.8 GeV/c^2 (right). The shadowed band represents the systematic error on the cocktail.

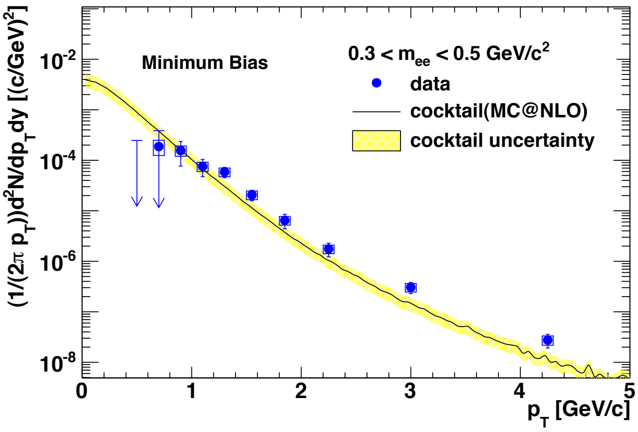

Figure 3: Acceptance corrected p_T spectra of e^+e^- pairs for $0.3 < m < 0.5$ GeV/c^2.