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PHENIX heavy-flavor results in d+Au collisions

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Charm and bottom quarks are found predominantly by gluon fusion in the initial hard scatterings of heavy-ions at RHIC, so they are good probes of the full medium evolution. In order to further understand the heavy quark dynamics in the hot medium, it is essential to study modifications due to the intrinsic nuclear matter so called cold nuclear matter effects. Deuteron(proton)-gold collisions are considered as a control experiment to study this kind of effects, but recent results from central $d(p)$+A collisions also suggest formation of a small thermalized system. The PHENIX experiment has an excellent ability to measure leptons decaying from charm/bottom hadrons at wide kinematic range. These results will be key measurements to understand evolution of medium effects from p+p collisions to heavy-ion collisions. In this talk, measurements of heavy quark production from p+p and d+Au collisions in PHENIX will be presented and discussed with several model calculations.

XXIII International Workshop on Deep-Inelastic Scattering,
27 April - May 1 2015
Dallas, Texas

[*]Speaker.

PoS(DIS2015)172

1. Introduction

Heavy quarks, mostly charm and bottom at RHIC energy, are produced by gluon fusion in the early stage of heavy-ion collisions. Therefore, they are good probes of full evolution of medium formed in heavy-ion collisions. The PHENIX experiment has good capabilities to study heavy quark production by measuring electrons at mid-rapidity ($|\eta| < 0.35$) and muons at backward and forward rapidity ($1.2 < |\eta| < 2.2$). Early heavy-flavor results in the PHENIX show a surprisingly large suppression of high p_T heavy-flavor electrons in central Au+Au collisions compared to the scaled $p+p$ results, which is consistent with the pQCD calculation [1]. Thanks to various beam species at RHIC, the medium effects on heavy quark production can be studied in different sizes of collision systems. Especially in d+Au collisions, initial-state effects, modifications due to the intrinsic properties of nucleus, are expected to be studied and help to interpret the results from heavy-ion collisions. However, recent interesting results in central d+Au collisions [2, 3] indicate a hydrodynamic behavior which has been believed as one property of the hot and dense medium in heavy-ion collisions.

2. Heavy-flavor results in d+Au collisions

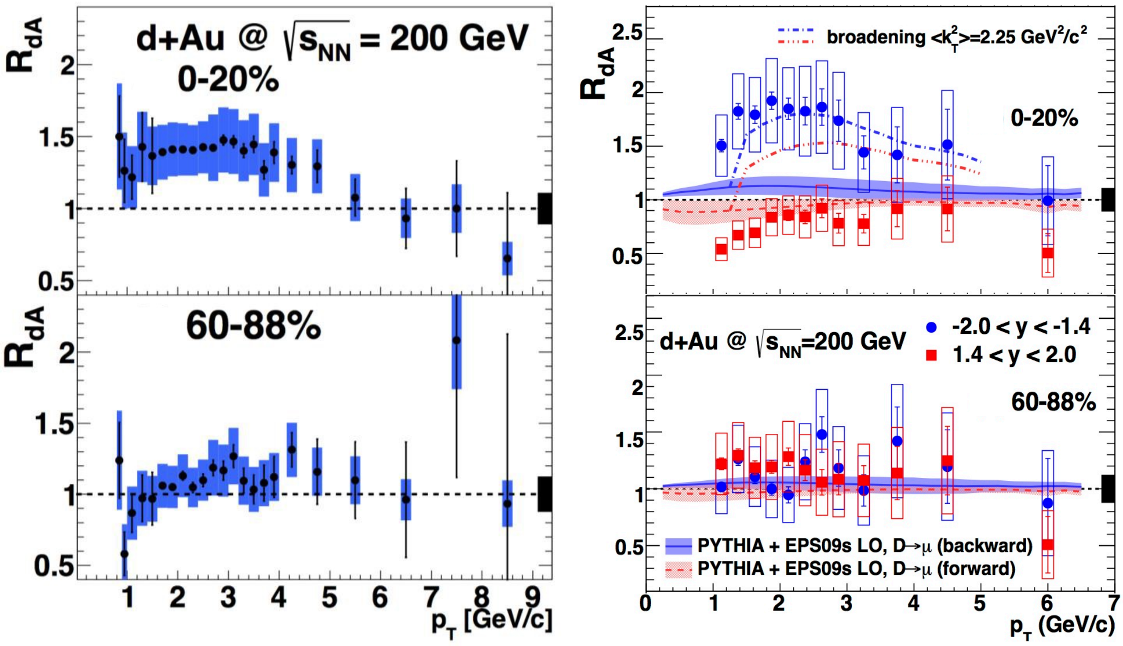

Figure 1: Nuclear modification factor $R_{d\mathrm{A}}$ of heavy-flavor electrons at mid-rapidity (left) and heavy-flavor muons at forward and backward rapidity (right) in 0–20% (top) and 60–88% (bottom) centrality classes.

PHENIX has obtained several heavy-flavor results in d+Au collisions with the large data sample collected during the RHIC Run-8. Figure 1 shows nuclear modification factor $R_{d\mathrm{A}}$ of heavy-flavor electrons at mid-rapidity (left) [4] and heavy-flavor muons at forward and backward rapidity (right) [5]. Upper panels show the results in the most central (0–20%) collisions, and lower panels present the results in the most peripheral (60–88%) collisions. $R_{d\mathrm{A}}$ in the most peripheral collisions at all rapidity regions are consistent with the scaled p+p results indicating no overall modification in this centrality class. However, clear modifications are seen in the central d+Au collisions. The production of heavy-flavor leptons are enhanced at mid and backward (Au-going direction) rapidity, whereas a suppression is observed at forward (d-going direction) rapidity. Model calculations considering initial-state effects are presented in the right panel. Any combinations of nuclear parton distribution functions and initial k_T broadening fail to reproduce the forward and backward data simultaneously. This might suggest that additional effects play a role in central d+Au collisions. A model calculation considering a charm radial flow successfully reproduce the enhancement at mid-rapidity [9]. In addition, a pQCD calculation including incoherent final-state multiple scatterings shows a consistent enhancement at backward rapidity [10].

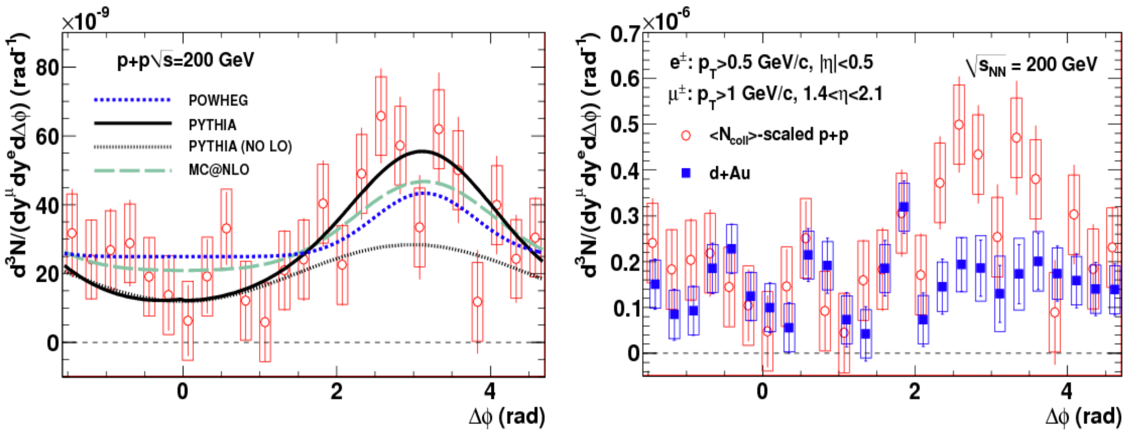

Figure 2: Heavy-flavor electron-muon pair yield in p+p collisions compared with model calculation (left) and comparison between the scaled p+p results and d+Au results.

The left plot in Fig. 2 shows azimutal angular correlations of heavy-flavor electrons (mid-rapidity) and muons (forward rapidity) in p+p collisions comparing to the results from several Monte Carlo event generators [6]. The results are consistent with the event generators, and the heavy-flavor electron-muon pairs is dominated by LO gluon fusion process by comparing the PYTHIA results with and without LO process. The right plot in Fig. 2 shows a comparison of heavy-flavor electron-muon pair production in p+p and d+Au collisions. In d+Au collisions, a nonzero correlation is still observed, but a back-to-back peak near $\delta\phi \approx \pi$ is clearly suppressed compared to the p+p results. This decorrelation might be due to the cold nuclear matter effects such as shadowing, saturation, and energy loss, but there is no model caluclation to reproduce this results yet.

It is interesting to compare the results of heavy-flavor leptons and J/ψ [7], because one possible different modification is a break-up effect on J/ψ production. Figure 3 shows $R_{d\mathrm{A}}$ of heavy-flavor leptons and J/ψ in central d+Au collisions, and each panel presents a comparison at different rapidity region. The forward rapidity results (right) are consistent with each other, but additioanl suppression of J/ψ is seen at backward (left) and mid-rapidity (center). These comparisons may suggest the nuclear break-up plays an important role in J/ψ production in d+Au collisions especially at mid and backward rapidity where the parton density is higher than that at forward region.

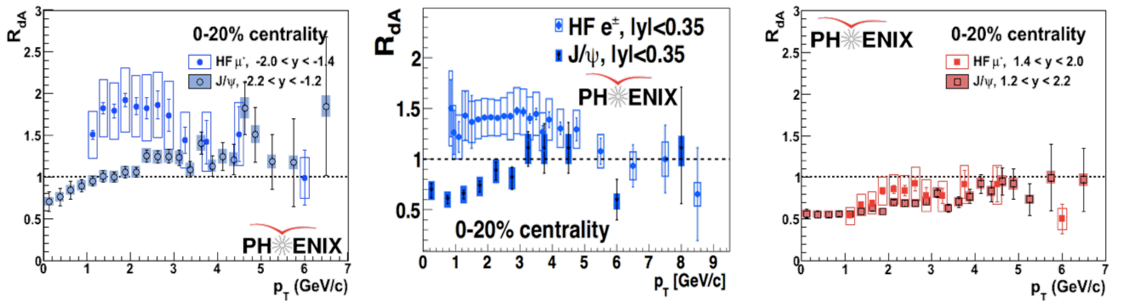

Figure 3: Comparions of nuclear modification factor $R_{d\mathrm{A}}$ between heavy-flavor leptons and J/ψ at backward (left), mid (center), and forward (right) rapidity regions.

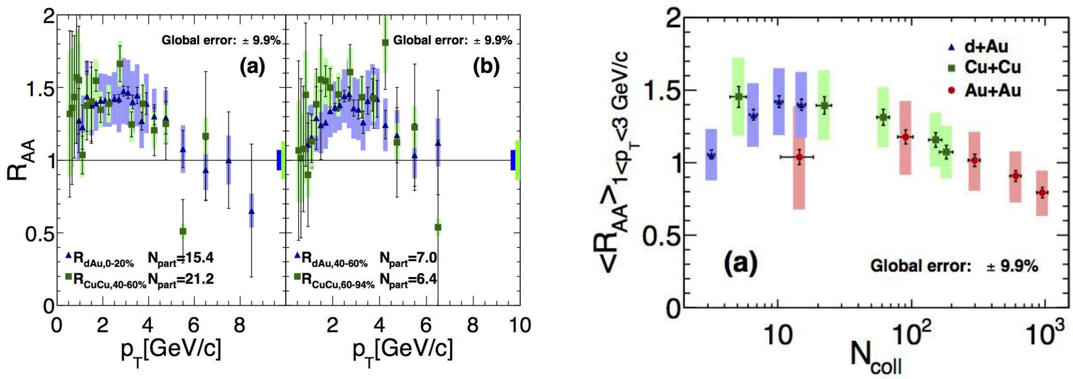

Figure 4: Nuclear modification factors of heavy-flavor electrons at mid-rapidity in d+Au and Cu+Cu collisions of similar number of participants (left) and nuclear modification factors as a function of the number of binary collisions in d+Au, Cu+Cu, and Au+Au collisions.

Figure 4 shows comparisons of nuclear modification factors in heavy-ion collisions. Two plots in the left panel show nuclear modification factors of heavy-flavor electrons at mid-rapidity in similar N_{part} of d+Au and Cu+Cu collisions [8]. The results from peripheral Cu+Cu collisions and central d+Au collisions show an similar enhancement. The right panel presents nuclear modification factors as a function of N_{coll} at mid-rapidity in all centrality classes of d+Au, Cu+Cu, and Au+Au collisions. This plot shows a nice trend of the no overall modification in the most peripheral d+Au results, the enhancement in central d+Au and peripheral Cu+Cu collisions, and the suppression in central Cu+Cu and Au+Au collisions.

3. Summary

PHENIX has measured heavy-flavor leptons in d+Au collisions at wide rapidity ranges. In the most peripheral collisions, there is no overall nuclear modification at all rapidity regions. However, clear modifications are observed in the most central d+Au collisions. There are enhancements in the intermediate p_T region at mid and backward rapidity, but a suppresion is seen at forward rapidity. The model calculations including initial-state effects fail to explain the data at forward and backward rapidity regions simultaneously. Other model calculations considering charm radial flow or final-state multiple scattering successfully reproduce the enhancement at mid and backward rapidity. These comparisons as well as recent long-range correlation results in central d+Au collisions may suggest final-state effects play a important role even in d+Au collisions. The enhancement seen in central d+Au collisions at mid-rapidity is consistent with the peripheral Cu+Cu results, where N_{part} of both collision systems are similar. As system size increases in central Cu+Cu and Au+Au collisions, suppression effects start to be dominant.

New silicon tracking systems, VTX and FVTX, has been successfully working and collected high quality p+p, p+Au, and Au+Au data. The enhanced position information will allow to measure charm and bottom production separately. These much precise measurements will help to improve the previous heavy-flavor results as well as advance our understanding of hot and cold nuclear matter effects on heavy quark production.

References

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