PROCEEDINGS OF SCIENCE

PHENIX measurements of charm, bottom and Drell-Yan via dimuons in p+p and p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

Yue Hang Leung[*†]
Stony Brook University
E-mail: yuehang.leung@stonybrook.edu

Dilepton spectra are a classic probe to study ultra-relativistic heavy ion collisions. At RHIC energies, the dimuon continuum is dominated by correlated pairs from semi-leptonic decays of charm and bottom hadrons and the Drell-Yan process. Heavy flavor angular correlations can be measured through dimuons, which can help constrain the relative contributions from different heavy flavor production mechanisms in p+p collisions, and may provide further insight on cold nuclear matter effects in p+Au collisions. Measurements of the Drell-Yan cross-section in p+Au collisions can provide constraints to nPDFs, and further our understanding in initial state effects. In this talk, we report recent measurements of $\mu\mu$ pairs from charm, bottom, and Drell-Yan in p+p and p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions
30 September - 5 October 2018
Aix-Les-Bains, Savoie, France

[*]Speaker.
[†]For the PHENIX collaboration.

PoS(HardProbes2018)160

1. Introduction

Despite substantial experimental and theoretical efforts in recent years, our understanding of heavy flavor production in p+p collisions remains incomplete. Heavy flavor cross section measurements, particularly for charm, are systematically higher than the central values of theoretical predictions for collision energies from the RHIC to the LHC, and are only consistent when large theoretical uncertainties are considered.

Angular correlations of the decay products from heavy flavor quarks and anti-quarks provide a unique handle for studying heavy flavor production in p+p collisions. Lepton pairs arising from leading order (LO) pair creation (PC) feature a strong back-to-back peak, whereas next-to-leading (NLO) processes, namely flavor excitation (FE) and gluon splitting (GS), produce broader azimuthal correlations. Thus, measuring angular correlations of heavy flavor decays in p+p collisions can help disentangle different heavy flavor production mechanisms, while similar studies in p+Au collisions may give insight on possible cold nuclear matter effects.

Besides heavy flavor, measurements of Drell-Yan cross sections in small systems provide valuable input to further our understanding in cold nuclear matter. As leptons pairs from the Drell-Yan process do not suffer final state interactions, it serves as a clean probe for initial state effects.

2. Heavy Flavor Angular Correlations in p+p and p+Au Collisions

PHENIX has recently measured differential cross-sections for $c\bar{c}$, $b\bar{b}$ and Drell-Yan production separately via dimuons [1], obtained from the large statistics data set of p+p collisions collected in 2015. Contributions from $c\bar{c}$, $b\bar{b}$ and Drell-Yan are separated via a simultaneous fit in mass and p_T utilizing both unlike- and like-sign muon pairs. The yield of like-sign pairs with mass greater 3.5 GeV/c^2 results predominantly from $b\bar{b}$, with negligible contribution from $c\bar{c}$ or Drell-Yan. By extrapolating to 4π phase space, the total bottom cross section is measured to be 3.75 ± 0.24 (stat) $^{+0.35}_{-0.50}$ (syst) $\pm$ 0.45 (global) μb. This measurement is consistent with previous measurements at the RHIC, and is approximately a factor of two higher than the central value from theoretical calculations.

For the unlike-sign pairs, it is found that the intermediate mass region ($1.5-2.5$ [GeV/c^2]) is dominated by $c\bar{c}$. To extract azimuthal correlations of the heavy flavor muon pairs, we select unlike-sign (like-sign) muon pairs in the mass region $1.5-2.5$ ($3.5-10.0$) [GeV/c^2] for $c\bar{c}$ ($b\bar{b}$). Background components are subtracted as a function of the azimuthal opening angle and the subtracted yields are corrected for efficiency. Fig. 1 shows the $c\bar{c}$ and $b\bar{b}$ differential yields as a function of the azimuthal opening angle. The data are compared to distributions generated from PYTHIA [2] and POWHEG [3]. The details of the settings for the simulations can be found in [1]. The generated distributions are normalized with the cross sections obtained from a simultaneous fit to the data and are indicated in Fig. 1. The χ^2/NDF value for $c\bar{c}$ ($b\bar{b}$) obtained by comparing data to PYTHIA is $20.14/14$ ($9.8/7$), which indicates that the data are well described by PYTHIA. The corresponding χ^2/NDF values from POWHEG is $35.8/14$ ($7.2/7$). Although POWHEG describes the $b\bar{b}$ data well, the distributions from POWHEG for $c\bar{c}$ are wider than those from the data.

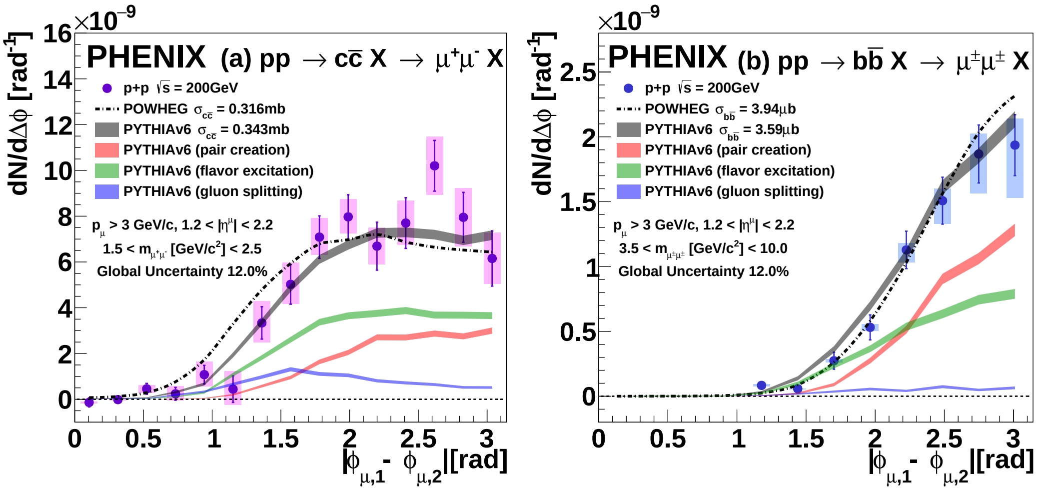

Figure 1: The corrected $\mu\mu$ yield as a function of azimuthal opening angle from (a) $c\bar{c}$ and (b) $b\bar{b}$ decays. The data are compared to the distributions calculated with PYTHIA [2] and POWHEG [3].

We compare generated distributions from PYTHIA and POWHEG, normalized with the same $c\bar{c}$ and $b\bar{b}$ cross-sections used for the comparison with the $\mu\mu$ data, with the previously measured $e\mu$ [4] and ee [5] heavy flavor yields. It is found that the distributions from PYTHIA are consistent with all data sets over this wide kinematic range, giving a χ^2/NDF of 59.6/47, whereas the distributions from POWHEG are broader than the data in all cases, and thus gives a higher χ^2/NDF value, 94.2/47.

A Bayesian analysis [6] is applied to all available data sets in order to extract the relative contributions from different heavy flavor production mechanisms, F_{PC}, F_{FE} and F_{GS}. Distributions from PC, FE and GS are generated using PYTHIA with Tune A settings [7] and the relative contribution from each process is allowed to vary. For $c\bar{c}$ production, we use the ee, $e\mu$ and $\mu^+\mu^-$ data sets; for $b\bar{b}$ we use the $\mu^\pm\mu^\pm$ data set. Credible intervals (C.I.) are constructed from the posterior probability densities, and are shown in Fig. 2.

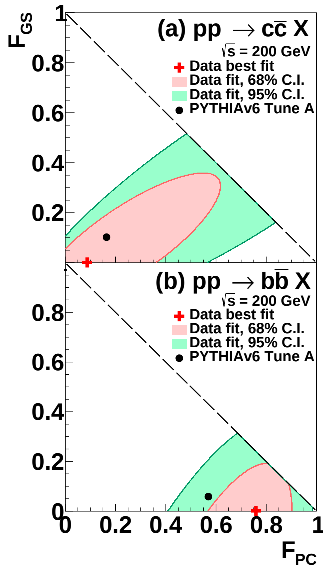

Figure 2: Credible intervals for (a) $c\bar{c}$ and (b) $b\bar{b}$ production mechanisms extracted from data and PYTHIA Tune A.

For $c\bar{c}$ and $b\bar{b}$, the relative fractions of each contribution calculated using the PYTHIA Tune A implementation lies within the 68% and 95% C.I. obtained from the analysis respectively. We infer from the posterior probability densities that for $c\bar{c}$, the hierarchy $F_{FE} > F_{PC} > F_{GS}$ is favored, consistent with the expectations from PYTHIA. For $b\bar{b}$, the results from the analysis indicate that the dominant ($76\% \pm^{14}_{19}\%$) production process is PC. In contrast to $c\bar{c}$, the ordering $F_{PC} > F_{FE} > F_{GS}$ is favored. The dominance of LO PC contribution for $b\bar{b}$ allows the study of initial gluon dynamics using bottom quarks as a probe, and provides the benefit of a cleaner interpretation of heavy ion data for $b\bar{b}$ production at RHIC energies. This contrasts to LHC energies where NLO processes are more important.

The analysis procedure for p+p collisions is applied to p+Au collisions at the same energy. The like-sign pair yield from $b\bar{b}$ as a function of the azimuthal opening angle are shown in Fig. 3, and compared to the binary scaled yield from p+p collisions. Within experimental uncertainties, no modification of the azimuthal correlations is found. The nuclear modification factor $R_{p+\mathrm{Au}}$ is also consistent with expectations from the modification of nPDFs estimated using EPPS16 [8]

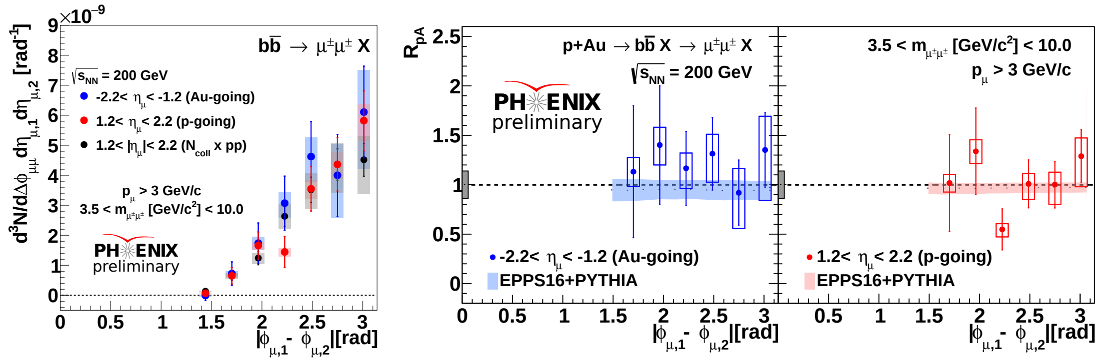

Figure 3: Left panels show the like-sign pair yield from $b\bar{b}$ in p+Au collisions as a function of the azimuthal opening angle (top) and pair p_T (bottom). Right panels show the ratio of the yields in p+Au collisions to binary scaled p+p collisions.

3. Drell-Yan cross sections in p+p and p+Au collisions

The high mass region ($4.8-8.2$ [GeV/c^2]) of the unlike-sign dimuon continuum is dominated by pairs from the Drell-Yan process. For the first time, the Drell-Yan cross sections in p+p and p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV are measured. The Drell-Yan differential cross sections per nucleon as a function of mass and as a function of p_T are shown in Fig. 4. The measured cross sections in p+p collisions are consistent with NLO calculations. For p+Au collisions, the $R_{p+\mathrm{Au}}$ is consistent with unity and EPPS16 for all data points to within experimental uncertainties. There is a hint of enhancement compared to p+p collisions for $p_T > 2$ GeV/c for the p-going side which may arise from initial state effects, unfortunately the large uncertainties in the data prohibits us from drawing any conclusions.

4. Summary

The first measurement of the dimuon continuum in p+p and p+Au collisions at RHIC is presented. In p+p collisions, the $b\bar{b}$ cross section is measured to be 3.75 ± 0.24 (stat) $^{+0.35}_{-0.50}$ (syst) 0.45 (global)[μb], around a factor of two higher than the central FONLL prediction. Based on the generated distributions of pair creation, flavor excitation and gluon splitting using PYTHIA Tune A, a Bayesian analysis is applied to all available heavy flavor lepton pair data at 200 GeV. The results support the scenario that the dominant source of $b\bar{b}$ production is leading order pair creation. The Drell-Yan cross section is consistent with NLO calculations. In p+Au collisions, the like-sign yield

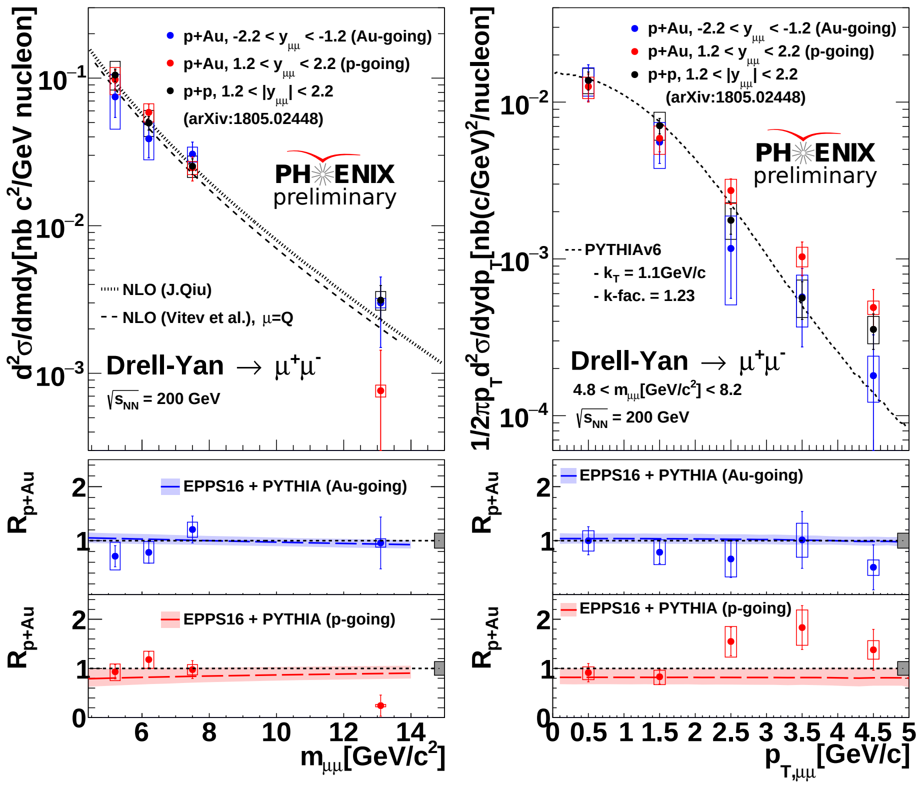

Figure 4: Drell-Yan cross sections as a function of mass (left) and p_T (right) in p+p (black) and p+Au (p-going (red), Au-going (blue)) collisions. The bottom panels show the nuclear modification factor for the Au-going side (blue) and the p-going side separately, and are compared to predictions from EPPS16.

from bottom shows no modification compared to p+p collisions. There is a hint of enhancement compared to p+p collisions for pairs from the Drell-Yan process at $p_T > 2$ GeV/c for the p-going side. To within the experimental uncertainties, the Drell-Yan cross sections per nucleon in p+Au collisions is consistent with those in p+p collisions.

References

[1] C. Aidala, et al., arXiv: 1805.02448.

[2] S. M. T. Sjostrand, P. Z. Skands, J. High Energy Phys. 05 (2006) 026.

[3] P. N. S. Frixione, G. Ridolf, J. High Energy Phys. 09 (2007) 126.

[4] A. Adare, et al., Phys. Rev. C89 (3) (2014) 034915.

[5] A. Adare, et al., Phys. Rev. C96 (2) (2017) 024907.

[6] C. Aidala, et al., arXiv: 1805.04075.

[7] R. D. Field, arXiv: hep–ph/0201192.

[8] K. J. Eskola, P. Paakkinen, H. Paukkunen, C. A. Salgado, Eur. Phys. J. C77 (3) (2017) 166.