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

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Abstract

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. The dimuon spectra contain information on heavy flavor angular correlations, which can constrain the relative contributions from different heavy flavor production mechanisms. Studying heavy flavor correlations in p+Au collisions may provide further insight on cold nuclear matter effects. Measurements of the Drell-Yan cross-section can provide constraints to PDFs, as well as further our understanding in initial state interactions in p+Au collisions.

In this talk, we report measurements of $\mu\mu$ pairs from charm, bottom, and Drell-Yan in p+p and p+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. A further shape analysis is applied to the heavy flavor pair correlations to extract the relative contributions to heavy flavor production mechanisms.

Keywords: heavy flavor, dileptons, PHENIX

1. Introduction

Heavy flavor production is a useful probe for studying the properties of the Quark-Gluon Plasma (QGP) created in heavy ion collisions. This is due to the fact that heavy quarks are primarily produced in the early stages of the collision. In addition to hot nuclear matter effects from the QGP, heavy flavor yields may also be modified due to cold nuclear matter effects such as (anti-)shadowing, initial and final state scattering, etc. Therefore, it is important to study heavy flavor production also in small collision systems in order to quantify these cold nuclear matter effects. In addition, gluon splitting processes in heavy flavor production complicates the interpretation of heavy flavor data in heavy ion collisions, since the gluon may be modified in the medium before splitting into a heavy quark pair. It is crucial to quantify the relative contributions of different heavy flavor production mechanisms, which can be studied in p+p collisions, in order to precisely interpret the heavy ion data.

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)

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pair creation (PC) feature a strong back-to-back peak, whereas next-to-leading (NLO) processes, namely flavor excitation (FE) and gluon splitting (GS) produces broader azimuthal correlations. Thus, measuring angular correlations of heavy flavor decays may help disentangle different heavy flavor production mechanisms.

2. The $\mu\mu$ pair yield from open heavy flavor in p+p collisions

Exploiting the large statistics data set of p+p collisions collected in 2015, PHENIX has measured differential cross-sections for $c\bar{c}$, $b\bar{b}$ and Drell-Yan production separately via dimuons [1]. A cocktail of all expected muon pair sources is generated; input p_T and rapidity spectra are constrained by existing data whenever possible. The cocktail is processed through a GEANT4 simulation and reconstruction chain which enables direct comparison to data. 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. It is found that the the yield of like-sign pairs with mass greater 3.5 GeV/c^2 results predominantly from $b\bar{b}$, while having negligible contribution from $c\bar{c}$ or Drell-Yan. This provides a strong constraint of the total bottom cross-section, which is measured to be 3.75 ± 0.24 (stat) ± $^{0.35}_{0.50}$ (syst) ± 0.45 (global) μb. This measurement is consistent with previous measurements at the Relativistic Heavy Ion Collider (RHIC) in the same system at the same collision energy, and is approximately a factor of two higher than the central value calculated with theoretical models.

For the unlike-sign pairs, it is found that the intermediate mass region (1.5 – 2.5 [GeV/c^2]) is dominated by $c\bar{c}$, while the high mass region (4.8 – 8.2 [GeV/c^2]) is dominated by the Drell-Yan process. To extract information on the correlations of the heavy flavor quarks, we select unlike- (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 subsequently corrected for efficiency. Fig. 1 shows the $c\bar{c}$ and $b\bar{b}$ differential yields as a function of the azimuthal opening angle.

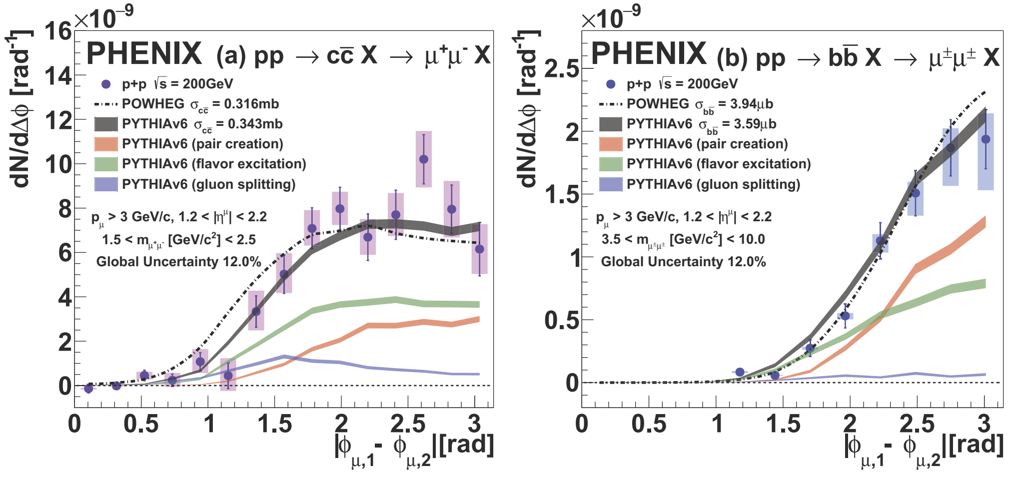

Fig. 1. The corrected $\mu\mu$ yield as a function of azimuthal opening angle from (a) $c\bar{c}$ and (b) $b\bar{b}$ decays. The data are compared to the distributions calculated with PYTHIA [2] and POWHEG [3].

The data are compared to distributions generated from PYTHIA [2] and POWHEG [3]. Detailed settings of the simulations can be found in [1]. The generated distributions are normalized with the cross-sections from the simultaneous fit procedure described above 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 broader than those from the data.

3. Correlations of $\mu\mu$, $e\mu$ and ee pairs and implications for $c\bar{c}$ and $b\bar{b}$ production

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 wider than the data in all cases, as is reflected by the higher χ^2/NDF value, 94.2/47.

A Bayesian analysis [6] is applied to all the 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.) constructed from the posterior probability densities are shown in Fig. 2.

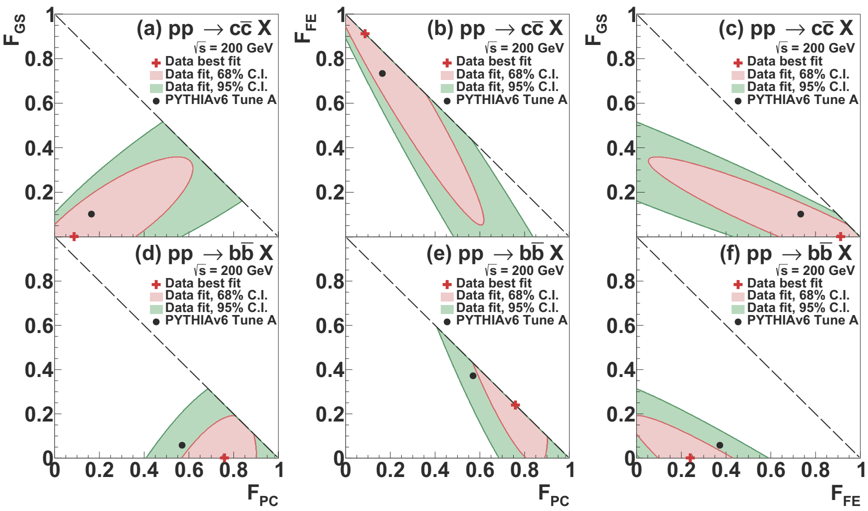

Fig. 2. Credible intervals for (a,b,c) $c\bar{c}$ and (d,e,f) $b\bar{b}$ production mechanisms extracted from data and PYTHIA Tune A.

For both $c\bar{c}$ ($b\bar{b}$), the relative fractions of each contribution calculated using the PYTHIA Tune A implementation lies within the 68% (95%) C.I. obtained from the analysis. 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 95% C.I. upper limits for F_{GS} for $c\bar{c}$ ($b\bar{b}$) are 52% (31%). The data supports the scenario of small GS contribution to $b\bar{b}$ production at 200 GeV. The dominance of LO PC contribution for $b\bar{b}$ allows the study of initial gluon dynamics using bottom quarks as a probe, as well as providing the benefit of a cleaner interpretation of heavy ion data for $b\bar{b}$ production at RHIC energies, in contrast to LHC energies where NLO processes are more important.

4. The $\mu\mu$ pair yield from $b\bar{b}$ in p+Au collisions

The analysis procedure for p+p collisions is applied to p+Au collisions at the same energy. The like-sign pair yield from $b\bar{b}$ is measured as a function the azimuthal opening angle and pair p_T as shown in Fig. 3, and compared to the binary scaled yield from p+p collisions.

Within the experimental uncertainties, no modification of the azimuthal correlations is found. In contrast, the pair p_T spectra from p+Au seem slightly softer in both the p- and the Au-going direction. The

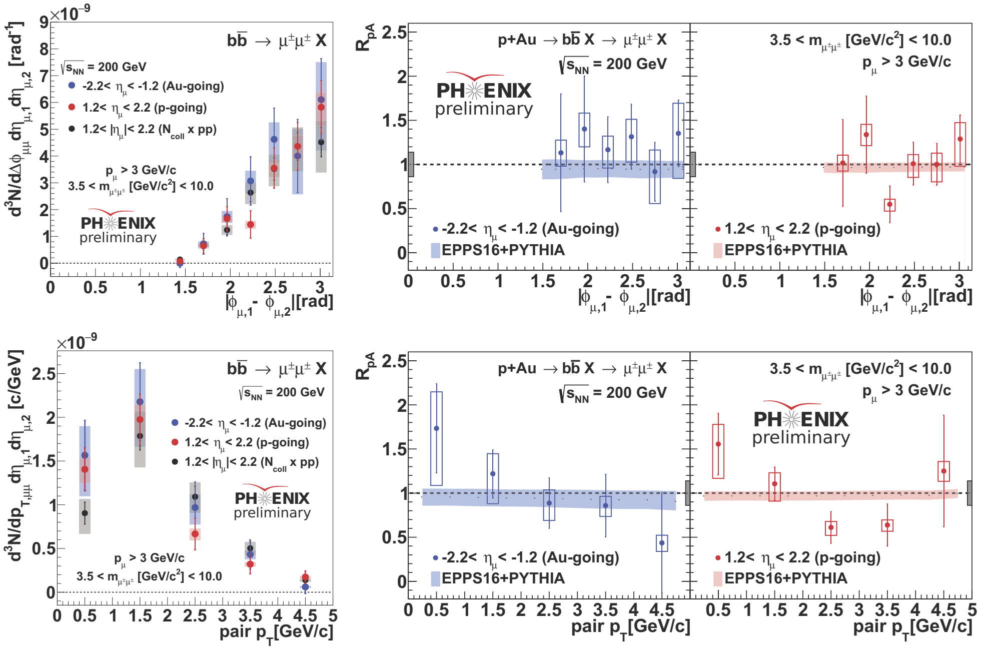

Fig. 3. Left panels show the like-sign pair yield from $b\bar{b}$ in p+Au collisions as a function of the azimuthal opening angle (top) and pair p_T (bottom). Right panels show the ratio of the yields in p+Au collisions to binary scaled $p+p$ collisions.

ratio of the yields in p+Au collisions to the binary scaled yield from $p+p$ collisions are shown in Fig. 3, and is compared to the expectations from the modification of nPDFs estimated using EPPS16 [8]. The R_{pA} estimated using EPPS16 does not show a decreasing trend as in the pair p_T data, which suggests the presence of additional cold nuclear matter effects, such as multiple scattering of partons traversing through nuclei.

5. 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) $\pm\, ^{0.35}_{0.50}$ (syst) ± 0.45 (global)[μb], around a factor of two higher than the central FONLL value. 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. In p+Au collisions, the like-sign yield from bottom shows a hint of enhancement at low pair p_T, followed by a decreasing trend. Further measurements of Drell-Yan and charm correlations in p+Au collisions should give more insight on cold nuclear matter effects.

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