Heavy Flavor Production in Heavy Ion Collisions at CMS

Jian Sun on behalf of the CMS Collaboration[*][†]

Purdue University (US)

E-mail: sun229@purdue.edu

Studies of Heavy flavor production are of great interest in heavy ion collisions. In the produced medium, the binding potential between a quark and antiquark in quarkonium is screened by surrounding light quarks and antiquarks. Thus, the various quarkonium states are expected to be melt at different temperatures depending on their binding energies, which allows us to characterize the QCD phase transition. In addition, open heavy flavor production are relevant for flavor-dependence of the in-medium parton energy loss. In QCD, gluons are expected to lose more energy compared to quarks when passing through the QGP due to the larger color charge. Compared to light quarks, heavy quarks are expected to lose less radiative energy because gluon radiation is suppressed at angles smaller than the ratio of the quark mass to its energy. This "dead cone effect" (and its disappearance at high transverse momentum) can be studied using open heavy flavor mesons and heavy flavor tagged jets. With CMS detector, quarkonia, open heavy flavor meson and heavy flavor tagged jet spectra are studied with high precision. In this talk, recent results from pp, pPb and PbPb at 2.76 and 5.02 TeV collisions are presented.

---

[*]Speaker.

[†]A list of members of the CMS Collaboration and acknowledgements can be found at the end of this issue.

1. Introduction

Because of their large mass, heavy quarks are primarily produced at early stages of heavy-ion collisions, and therefore experience the full evolution of the system, which makes them good probes of the Quark-Gluon plasma (QGP). The productions of various quarkonium states are ex-peced to be suppressed by the screening effect [1]. Furthermore, the various quarkonium states are expected to be melt at different temperatures depending on their binding energies, which allows us to characterize the QCD phase transition. In addition, open heavy flavor production are relevant for flavor-dependence of the in-medium parton energy loss. Compared with light quarks and glu-ons, heavy quarks are expected to lose less energy due to color charge and dead cone effect [2]. Furthermore, study of heavy quarks can also help us understand the cold nuclear matter effects [3].

The CMS experiment is a general-purpose detector with large acceptance and good perfor-mance on reconstruciton of track, muon, jets, etc. In CMS, heavy quarkonium is mainly studied through dilepton decay channels. The open heavy flavor is studied through reconstructed D and B hadrons, J/ψ from B hadron decay, and heavy flavor jets. In this article, Sec. 2 and 3 present the measurements of quarkonia and open heavy flavor with CMS, respectively.

2. Quarkonia Measurements

The left panel of Figure 1 shows the $\Upsilon(nS)/\Upsilon(1S)$ ratio as a function of event multiplicity in 2.76 TeV pp and 5.02 TeV pPb collisions [4]. The $\Upsilon(nS)/\Upsilon(1S)$ ratio is found to decrease toward higher multiplicity, which indicates there are effects in small systems to be further studied. The right panel shows the prompt J/ψ $R_{FB} = \frac{d^2\sigma(y_{CM}>0)/dp_Tdy_{CM}}{d^2\sigma(y_{CM}<0)/dp_Tdy_{CM}}$ as a function of p_T in pPb collisions at 5.02 TeV [5]. The prompt J/ψ production in $y_{CM} > 0$ region is found to be suppressed compared with $y_{CM} < 0$ region, which is due to cold nuclear matter effects or a combination of cold nuclear matter effects and other effects.
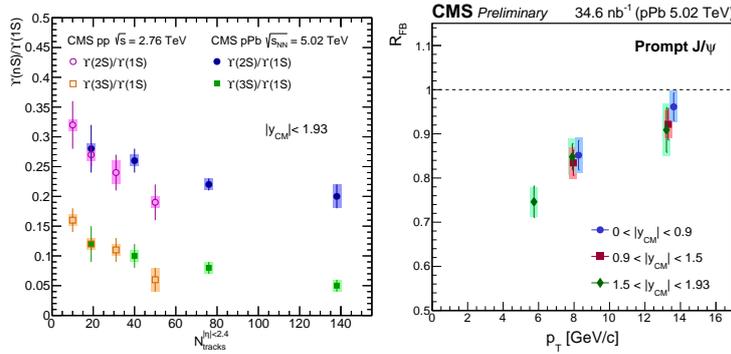

Figure 1: (Left) $\Upsilon(nS)/\Upsilon(1S)$ ratio as a function of $N_{tracks}^{|\eta|<2.4}$ in 2.76 TeV pp and 5.02 TeV pPb collisions for $\Upsilon(2S)$ and $\Upsilon(3S)$ in $|y_{CM}| < 1.93$. (Right) Prompt J/ψ R_{FB} as a function of p_T in different y_{CM} regions.

Figure 2 shows prompt J/ψ R_{AA} (left) and v_2 (right) as a function of N_{part} for the p_T range 6.5 GeV/c to 30.0 GeV/c in PbPb collisions at 2.76 TeV [6]. The prompt J/ψ production is significantly suppressed in PbPb collisions and the suppression has a clear centrality dependence. The prompt J/ψ v_2 is found to be positive in studied p_T range, which indicates the path length dependence of energy loss.
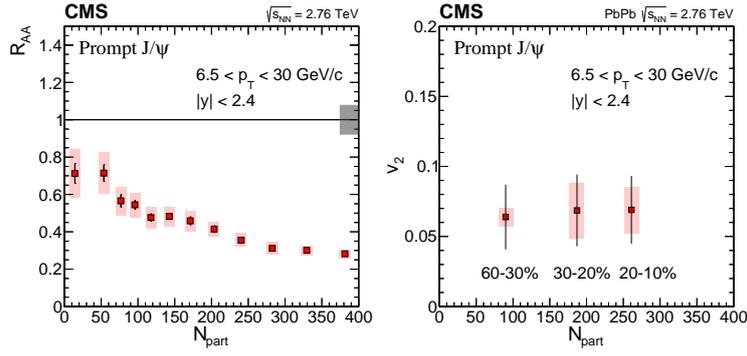
Figure 2: Prompt J/ψ R_{AA} (left) and v_2 (right) as a function of N_{part} in PbPb collisions at 2.76 TeV.

Figure 3 shows R_{AA} of $\Upsilon(1S)$ and $\Upsilon(2S)$ as functions of p_T (left) and N_{part} (right) in PbPb collisions at 2.76 TeV [7]. The R_{AA} of $\Upsilon(2S)$ is smaller than the R_{AA} of $\Upsilon(1S)$, which is consistent with the fact that the binding energy of $\Upsilon(1S)$ is bigger than that of $\Upsilon(2S)$. The suppression of $\Upsilon(1S)$ and $\Upsilon(2S)$ is found to have a clear centrality dependence and little dependence on p_T .
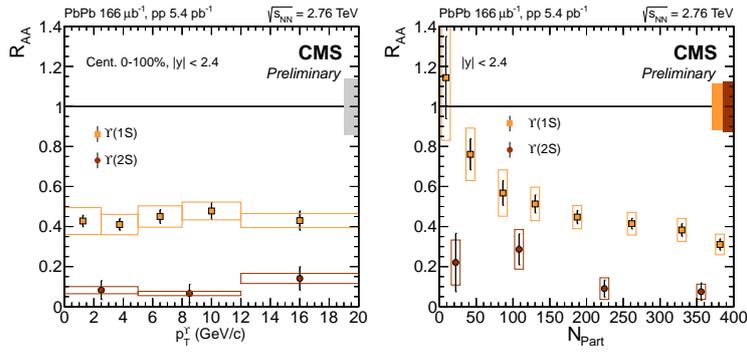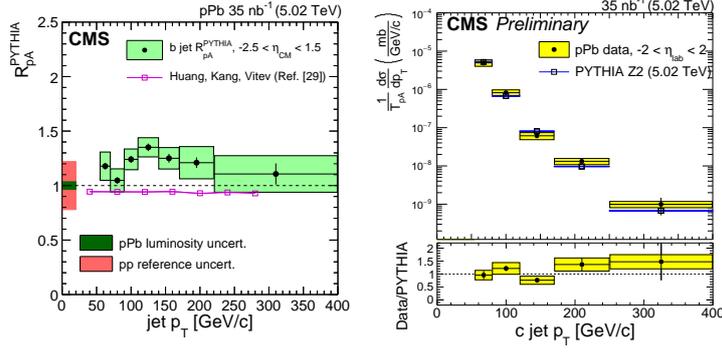

Figure 3: R_{AA} of $\Upsilon(1S)$ and $\Upsilon(2S)$ as functions of p_T (left) and N_{part} (right) in PbPb collisions at 2.76 TeV.

3. Open Heavy Flavor Measurements
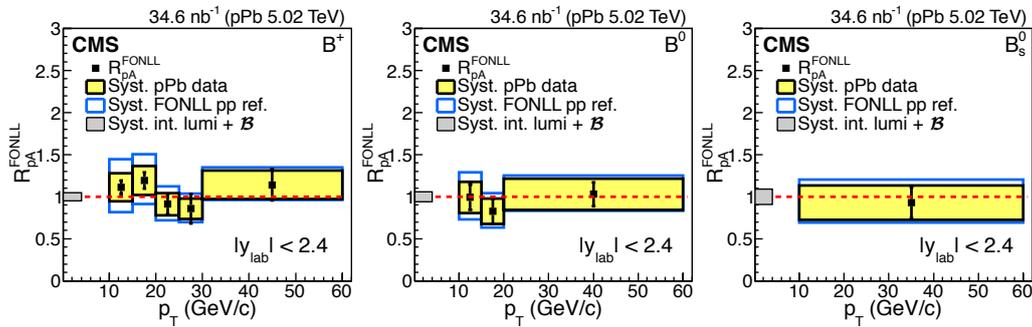
Figure 4: R_{pA}^{FONLL} of B^+ (left), B^0 (middle) and B_s^0 (right) mesons in $|y_{lab}| < 2.4$ as a function of p_T in pPb collisions at 5.02 TeV.

Figure 5: (Left) b-jet R_{pA}^{PYTHIA} as a function of p_T in pPb collisions at 5.02 TeV. (Right) c-jet invariant yield scaled by T_{pA} as a function of p_T in pPb collisions at 5.02 TeV. PYTHIA calculation is also shown for comparison.

The cold nuclear matter effects are studied with the B mesons, b-jet and c-jet production in pPb collisions at 5.02 TeV. The R_{pA}^{FONLL} of B mesons is found to be consistent with unity within uncertainties as showed in Figure 4 [8]. The R_{pA}^{PYTHIA} of b-jet and c-jet is also found to be consistent with unity within uncertainties as showed in Figure 5 [9]. Thus, no significant cold nuclear matter effects are observed in these measurements and cold nuclear matter effects should not play an important role in heavy flavor production at high p_T in AA collisions.

Figure 6 shows prompt D^0 R_{AA} as a function of p_T for centrality classes 0-100% (left) and 0-10% (right) in PbPb collision at 5.02 TeV [10]. Compared with previous measurement of prompt D^0 R_{AA} at 2.76 TeV with CMS [11], the significant improvement is that the reference of the new R_{AA} results is measured pp reference at the same energy. The suppression of D^0 at 5.02 TeV is found to be consistent with the suppression at 2.76 TeV. It is found that the prompt D^0 R_{AA} is close to charged particle R_{AA} and they have similar p_T dependence.
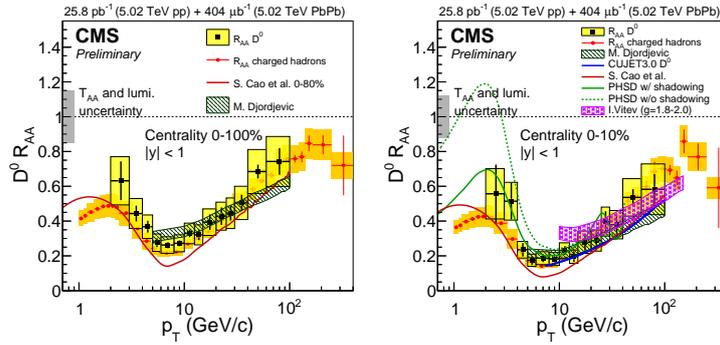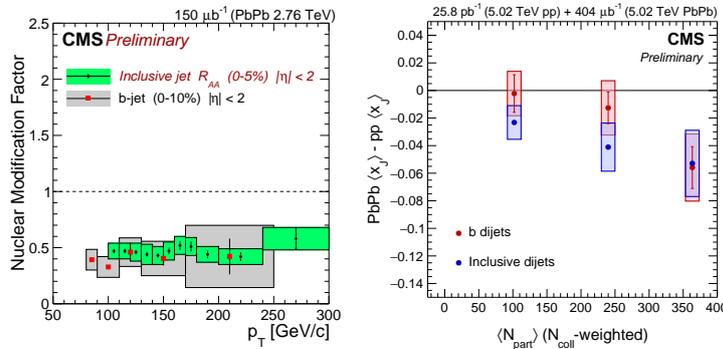

Figure 6: Prompt D^0 R_{AA} as a function of p_T for centrality classes 0-100% (left) and 0-10% (right) in PbPb collision at 5.02 TeV. The charged particle R_{AA} and model predictions are shown for comparison.

The left panel of Figure 7 shows nonprompt J/ψ R_{AA} as a function of p_T in PbPb collisions at 2.76 TeV [6]. The suppression of nonprompt J/ψ is found to be stronger with increasing p_T. The right panel shows prompt D^0 R_{AA}^*, charged particle R_{AA}, and non-prompt J/ψ R_{AA} as function of N_{part} in PbPb collisions at 2.76 TeV [11], which indicates the prompt D^0 is more suppressed than non-prompt J/ψ. The results are consistent with calculations by Djordjevic et al. [12].

3
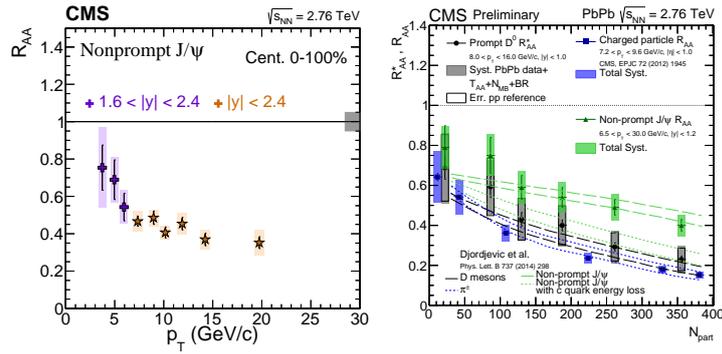
Figure 7: (Left) Nonprompt J/ψ R_{AA} as a function of p_T in PbPb collisions at 2.76 TeV. (Right) Comparison of prompt D^0 R^*_{AA} with charged particle R_{AA} and non-prompt J/ψ R_{AA} as function of N_{part} in PbPb collisions at 2.76 TeV. The measurements are also compared with calculations.

Figure 8: (Left) b-jet R_{AA} as a function of p_T for centrality class 0-10% in PbPb collisions at 2.76 TeV. The measurement of inclusive jet R_{AA} is also plotted for comparison. (Right) Mean x_J difference between PbPb and pp at 5.02 TeV for inclusive dijets and b dijets for different centrality classes of PbPb collisions.

The left panel of Figure 8 shows the b-jet R_{AA} as a function of p_T for centrality class 0-10% in PbPb collisions at 2.76 TeV [13]. It is found the R_{AA} of b-jet is consistent with R_{AA} of inclusive jets within uncertainties. Gluon splitting process is a big component and flavor creation process is not the dominant component in b-jet production at 2.76 TeV, thus it is difficult to conclude the flavor dependence energy loss from the comparsion of R_{AA}. To further study the flavor dependence energy loss, the b-dijets imbalance is studied in PbPb collisions at 5.02 TeV and compared with the imbalance of inclusive dijets [14], where flavor creation process is the dominant component. The b-dijets imbalance is found to be at similar level as the inclusive dijets imbalance as shown in the right panel of Figure 8.

4. Summary

This paper presents the CMS measurements of quarkonia and open heavy flavor in pp, pPb, and PbPb collisions at 2.76 and 5.02 TeV. Both cold nulecar matter effects and final state effects are

studied with the measurements, which provides insight into the understanding of the interactions between heavy quarks and the medium.

References

[1] T. Matsui and H. Satz. J/ψ Suppression by Quark-Gluon Plasma Formation. *Phys. Lett.*, B178:416–422, 1986.

[2] Yuri L. Dokshitzer and D. E. Kharzeev. Heavy quark colorimetry of QCD matter. *Phys. Lett.*, B519:199–206, 2001.

[3] F. Dominguez, D. E. Kharzeev, E. M. Levin, A. H. Mueller, and K. Tuchin. Gluon saturation effects on the color singlet J/ψ production in high energy dA and AA collisions. *Phys. Lett.*, B710:182–187, 2012.

[4] Serguei Chatrchyan et al. Event activity dependence of Y(nS) production in $\sqrt{s_{NN}}$=5.02 TeV pPb and $\sqrt{s}$=2.76 TeV pp collisions. *JHEP*, 04:103, 2014.

[5] J/ψ production in pPb collisions. Technical Report CMS-PAS-HIN-14-009, CERN, Geneva, 2015.

[6] Vardan Khachatryan et al. Suppression and azimuthal anisotropy of prompt and nonprompt J/ψ production in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. 2016.

[7] Nuclear modification of Y states in PbPb. Technical Report CMS-PAS-HIN-15-001, CERN, Geneva, 2015.

[8] Vardan Khachatryan et al. Study of B Meson Production in p+Pb Collisions at $\sqrt{s_{NN}} = 5.02$ TeV Using Exclusive Hadronic Decays. *Phys. Rev. Lett.*, 116(3):032301, 2016.

[9] Vardan Khachatryan et al. Transverse momentum spectra of inclusive b jets in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. *Phys. Lett.*, B754:59, 2016.

[10] D^0 meson nuclear modification factor in PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. Technical Report CMS-PAS-HIN-16-001, CERN, Geneva, 2016.

[11] Nuclear Modification Factor of prompt D^0 in PbPb Collisions at 2.76 TeV. Technical Report CMS-PAS-HIN-15-005, CERN, Geneva, 2015.

[12] Magdalena Djordjevic, Marko Djordjevic, and Bojana Blagojevic. RHIC and LHC jet suppression in non-central collisions. *Phys. Lett.*, B737:298–302, 2014.

[13] Serguei Chatrchyan et al. Evidence of b-Jet Quenching in PbPb Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. *Phys. Rev. Lett.*, 113(13):132301, 2014. [Erratum: Phys. Rev. Lett.115,no.2,029903(2015)].

[14] Transverse momentum balance of b-jet pairs in PbPb collisions at 5 TeV. Technical Report CMS-PAS-HIN-16-005, CERN, Geneva, 2016.