EPJ Web of Conferences **141**, 05008 (2017) DOI: 10.1051/epjconf/201714105008
ISMD 2016

Measurement of bottomonia states in pp, pPb and PbPb collisions at 2.76 TeV from CMS

Yongsun Kim on behalf of the CMS collaboration[1]

[1] *Korea University, 145 Anam-ro, Seonbuk-gu, Seoul, Republic of Korea*

Abstract. The modification of jets in heavy ion collision at a center of mass energy of $\sqrt{s_{NN}}$ = 2.76 TeV was observed via various analyses carried out with Run I LHC data. In November 2015, LHC delivered the Run II phase lead-lead beams at 5.02 TeV and proton-proton beams at the same energy for reference. The high luminosity PbPb data, more than twice of the previous run, provided an opportunity for elaborate studies based on high-pt probes. This presentation discusses the development of jet finding algorithms and jet observables, including the production rates, fragmentation patterns, and flavor dependence, published by CMS, ALICE and ATLAS collaborations. The results from 2.76 TeV data are briefly reviewed, followed by a presentation of the most recent results from $\sqrt{s_{NN}}$ = 5.02 TeV.

1 Introduction

At extremely high temperature, the quarks and gluons are expected to be deconfined from hadronic states and matter to transit to a new thermal system, a Quark-Gluon Plasma (QGP). A QGP state is predicted to be produced in a laboratory by colliding relativistically accelerated heavy ions. Measurement of high p_{T} probes is of big interest because it can characterize the QGP in several aspects. The suppression of the high p_{T} jets is one of the main evidence of QGP formation because an energetic parton would lose its energy as it traverses the medium. As a result, that parton becomes a jet with lower p_{T} compared to what it is supposed to be in vacuum. Moreover, the jet has been one of the most popular physics object in Heavy Ion community at LHC because of the high production cross section and the advanced detection technologies. Since the first PbPb collisions in 2010, many papers and preliminary notes have been published by LHC heavy ion experiments to quantify the energy loss of high p_{T} jets. In addition, it was also found that the jets are modified even in pPb collisions, by so-called the cold nuclear matter (CNM) effects. The CNM effects include the modification of the parton distribution function, Cronin effect and nuclear absorption. During the Run I period, the pPb collisions were carried out at $\sqrt{s_{NN}}$ = 5.02 TeV and pp and PbPb are measured at $\sqrt{s_{NN}}$ = 2.76 TeV.

 DOI: 10.1051/epjconf/201714105008

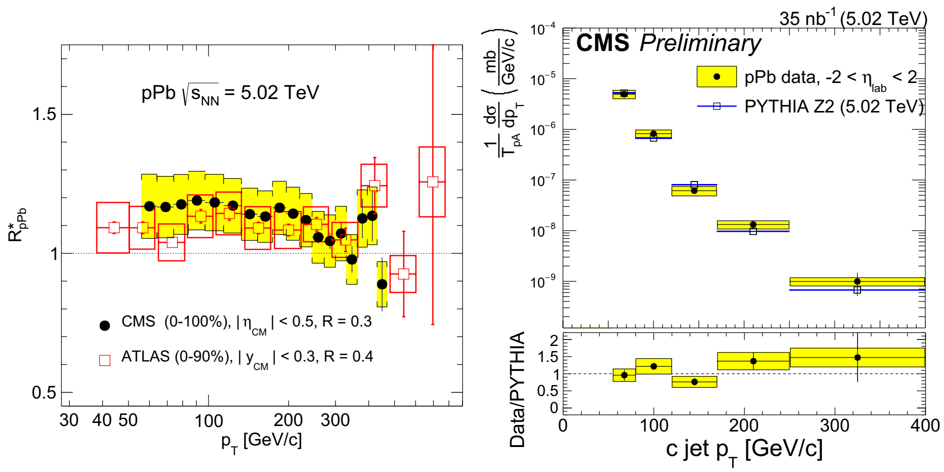

Figure 1. (Left) $R_{\rm pA}$ of inclusive jets measured by ATLAS and CMS (in different jet radius) [3]. (Right) Ratio of cross-sections of b jet in pPb to calculations by PYTHIA generator, after scaling by the nuclear overlap factor from the Glauber model [4].

2 Jets in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

2.1 $R_{\rm pA}$ of inclusive jets and heavy flavored jets

The spectra of jet in pPb and pp systems were compared, as one of the conventional methods to measure the nuclear matter effect. $R_{\rm pA}$, which is the ratio of production cross sections in pPb to pp normalized by the binary nucleon-nucleon collisions, was measured by both CMS [1] and ATLAS [2]. The same jet reconstruction algorithm (anti-k$_{\rm T}$) were used with different jet cone radii: 0.3 for CMS, and 0.4 for ATLAS. As shown in Fig. 1, the measured $R_{\rm pA}$ is consistent in 1 - 1.5 σ level depending on $p_{\rm T}$. This result confirms that the strong suppression of jets discovered in PbPb collisions is due to the hot and dense medium effect. Compared to various theoretical models, the CMS result of $R_{\rm pA}$ favors the NLO calculation with EPS09 nPDF. ATLAS also measured the jet $R_{\rm pA}$ and $R_{\rm CP}$ (Central-to-Peripheral ratio) as a function of the pPb centrality and observed a strong reduction of jet yields pronounced at high $p_{\rm T}$ above 200 GeV/c in the most central events. CMS also measured the spectra of jets from bottom quarks [5] and charm quarks [6] using the heavy quark tagging technique based on the the secondary vertex reconstruction. As displayed in Fig. 1, the production rate of heavy quark jets is consistent to the Monte Carlo calculation from PYTHIA generator within the measured uncertainties.

2.2 Dijet pair and nPDF

Besides the inclusive jet studies, the dijet events in pPb collision can be good probes for the nPDF because they provide two-dimensional information: the average value of pseudo-rapidities and the mean $p_{\rm T}$ reflect the x and Q^2 in the PDF respectively. The CMS collaboration made a thorough measurement of di-jet pairs in pPb and pp from the recent Run II data, and provided a strong constraint for nPDF models [7]. Fig. 2 is one example.

[a] e-mail: kimy@cern.ch

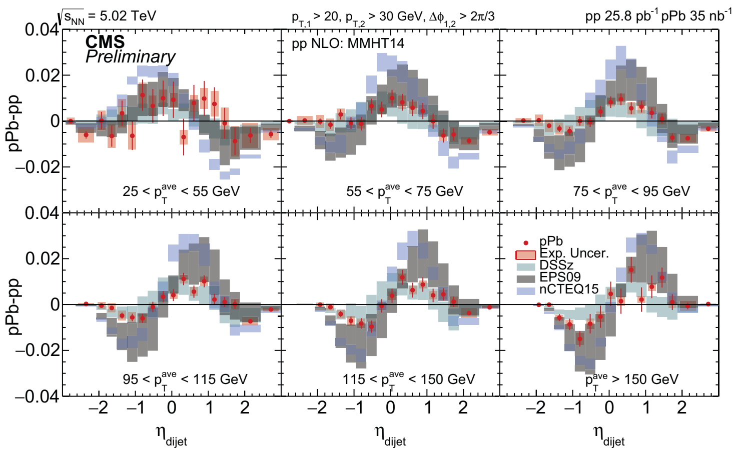

Figure 2. The difference of dijet pseudo-rapidity distributions between pPb and pp in bins of average p_T of dijet pairs [8]. The results are compared to NLO calculations based on nPDF sets DSSZ, EPS09 and nCTEQ15 and proton PDF MMHT14.

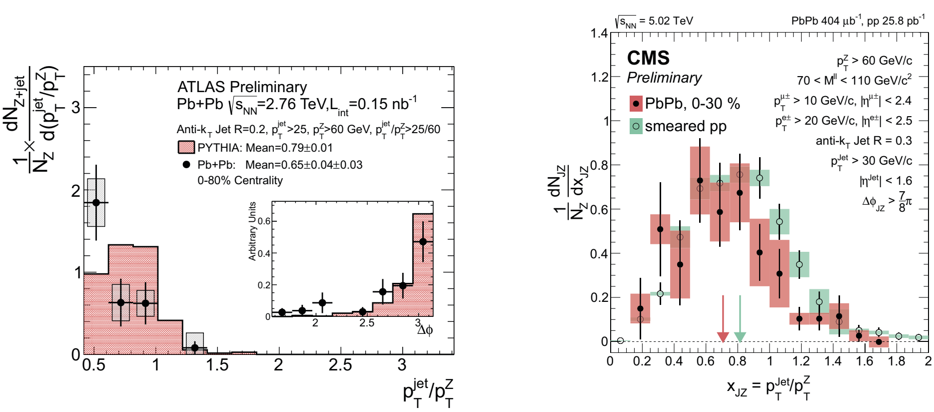

Figure 3. Transverse momentum ratio X_{JZ} between the Z boson and the jets with the azimuthal angle separation $\Delta\phi > 7\pi/8$, measured in ATLAS (Left) [9] and CMS (Right) [10].

3 Jet quenching in PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

3.1 Photon-jet and Z-jet correlation

The observable of the first jet quenching measurement from CMS Run II data was correlation in Z-jet pairs [11]. The Z boson, like direct photons in γ-jet channel, is color blind. For this reason, the direct comparison of the p_T of a Z boson to the momentum of associated jets provides the information of energy loss of jets. The distribution of p_T ratio between Z and jet was found to be in the similar level of the γ-jet result in the same kinematic range [12] as shown in Fig. 3. Despite its statistical limit, this measurement can be recognized as a meaningful study because it demonstrates the utility of Z

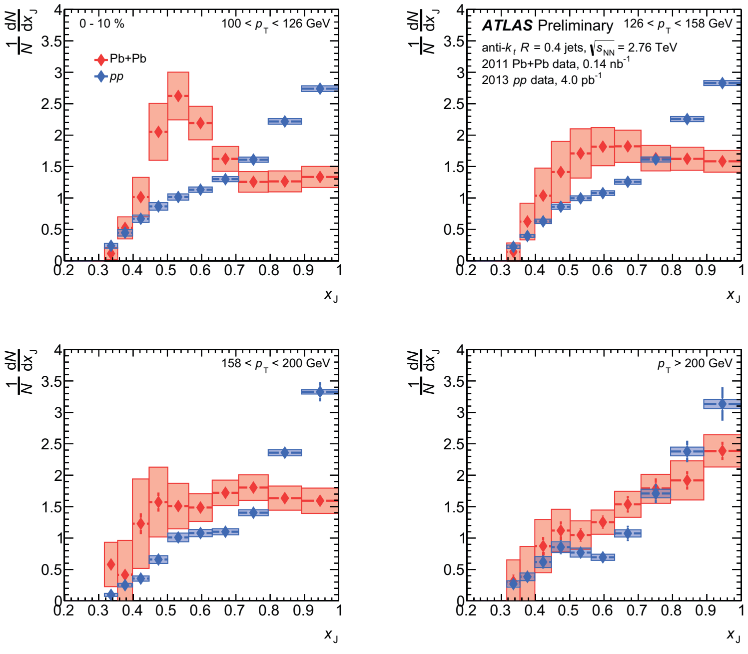

Figure 4. The (1/N)dN/dx distributions for different selections on leading jet p_T in 0-10% PbPb events (red) and pp (blue). [13]

bosons for quantitative study of jet quenching. A similar measurement was performed by ATLAS at 2.76 TeV [14].

3.2 Di-jet results

Since the first heavy ion collisions at LHC, several analyses were carried out using the back-to-back dijet pairs in PbPb and pp. Recently ATLAS published the momentum asymmetry results in PbPb, where the jet energy resolution effects are fully unfolded [13]. From the distribution of $x_J = p_T^{subleading\,jet}/p_T^{leading\,jet}$ in 0-10% central collisions, a clear peak was observed around $x_J = 0.5$ which provides a constraint in the modeling of jet quenching.

3.3 Jet-track correlation

In order to chase the missing energy dissipated by the jet quenching effect, several analyses of jet-track correlation were carried by the CMS collaboration. In this note, three publications are highlighted. In the first paper [15], the p_T distribution of charged particles in dijet events are studied. The p_T distribution of tracks projected to the jet axis are measured. The integration of the projected p_T values turned out to make up the momentum imbalance of the dijet pair. The redistribution pattern of momentum was also studied for different centrality bins using various selection of radius in jet reconstruction algorithm. In the second analysis [16], the momentum distribution of hadrons are compared for those in peak region ($(|\Delta\eta| < 1.5$) and in long-range region ($1.5 < |\Delta\eta| < 2.5$). In Fig 5,

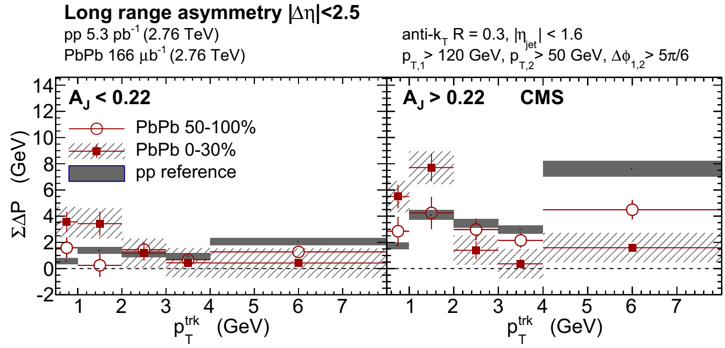

Figure 5. Integrated p_{T} of tracks in long-range correlated tracks as a function of p_{T}^{trk} integrated over $|\Delta\phi| < \pi/2$ and $|\Delta\eta| < 2.5$ for pp, peripheral PbPb and central PbPb data balanced dijet events (Left) and unbalanced for dijet events (Right). [16]

the momentum of charged tracks are integrated in the hemisphere of $|\Delta\eta| < 2.5$ and $|\Delta\eta| < 1.5$) for each p_{T} bins of tracks. For unbalanced dijet events ($\mathrm{A_J} > 0.22$),an assymetry was observed for overall range of p_{T} . For balanced dijet events $\mathrm{A_J} < 0.22$, clear modification was observed in p_{T} range below 2 GeV/c. In the third anlaysis [17], a full census of $\Delta\eta$ and $\Delta\phi$ of track-jet pairs are taken for leading jet and subleading jet for several track and jet p_{T} bins. A clear modification of distributions is found for PbPb results compared to pp.

3.4 Study of jet splitting

The jet splitting is one of new measurement done by CMS using 5.02 TeV Run II data. Jets reconstructed by anti-kT algorithm and then the internal jet structure is divided into two smaller jets by running the kT algorithm inside. Novel techniques, such as jet Grooming and sub-jet finding algorithms [19], were used for this analysis. The main physics observable is $\mathrm{z_g} = \min(\mathrm{p_T^1}, \mathrm{p_T^2})/(\mathrm{p_T^1} + \mathrm{p_T^2})$, where p_{T}^1 and p_{T}^2 are the transverse momentum of two branches of a jet. As shown in Fig. 6, the distribution of $\mathrm{z_g}$ was measured in 4 different centrality bins in PbPb data and in pp data, and their ratio was used to quantify the difference of the splitting patterns. In the central PbPb collisions, the fraction of imbalanced branches were enhanced and balanced cases were suppressed compared to pp result. And, the result in the most peripheral PbPb collision was consistent to pp data within the uncertainties. It was also observed that such a modification is less conspicuous for higher jet p_{T} selection.

4 Summary

The heavy ion jet results at 2.76 TeV and 5.02 TeV from CMS and ATLAS collaboration were reviewed. The pPb result of nuclear modification factor for inclusive, b-tagged and c-tagged jets confirms that the strong suppression in PbPb collision is attributed to the hot medium effects. The analysis on dijet pair provided a strong constraint for nPDF in anti-shadowing regime. The jet quenching effects at 2.76 TeV are measured in several hard probe channels including dijet, photon-jet and Z-jet. Plus, the precision measurement to change the missing energy was done by studying the jet-track correlation. In addition, many results using the new data at 5.02 TeV from LHC Run II have been released. The Z-jet result proved the role of Z bosons for elaborate jet quenching analyses in near

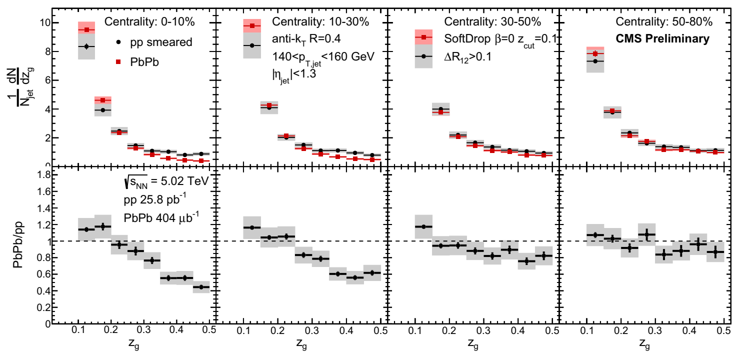

Figure 6. Splitting function of jets in PbPb for $140 < p_T < 160$ GeV/c in several centrality ranges compared to pp data. [18]

future. And the jet splitting phenomena measured using the sub-jet finding technique shed light on the modification of hadronization pattern of jets at early stage.

References

[1] CMS Collaboration, EPJC 76 (2016) 372.
[2] ATLAS Collaboration, EPLB 748 (2015) 392.
[3] CMS Collaboration and ATLAS Collaboration, Retrieved from http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN-14-001/.
[4] CMS Collaboration, Retrieved from http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN-14-007/.
[5] CMS Collaboration, PLB 754 (2016) 59.
[6] CMS Collaboration, CMS-HIN-15-012 (2015).
[7] CMS Collaboration, CMS-PAS-HIN-16-003 (2016).
[8] CMS Collaboration, Retrieved from https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIN-16-003/index.html.
[9] ATLAS Collaboration, Retrieved from https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-119/.
[10] CMS Collaboration, Retrieved from https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIN-16-002/index.html.
[11] CMS Collaboration, CMS-PAS-HIN-15-013 (2016).
[12] CMS Collaboration, CMS-PAS-HIN-13-006 (2016).
[13] ATLAS Collaboration, ATLAS-CONF-2015-052 (2015).
[14] ATLAS Collaboration, ATLAS-CONF-2012-119 (2012).
[15] CMS Collaboration, JHEP 01 (2016) 006.
[16] CMS Collaboration, CMS-HIN-15-011 (2016).
[17] CMS Collaboration, JHEP 1602 (2016) 156.
[18] CMS Collaboration, CMS-PAS-HIN-16-006 (2016).
[19] CMS Collaboration, Retrieved from https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIN-16-006/index.html.