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Nuclear modification of hadron and jet spectra with CMS

Marguerite Belt Tonjes for the CMS Collaboration

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The Compact Muon Solenoid (CMS) experiment measures various stages of nuclear collisions utilizing the different types of beams from the Large Hadron Collider (LHC). PbPb collisions can provide remarkable insight into the final state effects, such as jet quenching. However, recent studies of pPb collisions shed light on initial state effects and complement a chronological picture of the nuclear interaction. CMS results of jet and hadron measurements in such collisions are presented.

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Nuclear modification of jet and hadron spectra with CMS

Marguerite B. Tonjes, for the CMS Collaboration
University of Maryland, College Park, MD, 20742, U.S.A.

Abstract

The Compact Muon Solenoid (CMS) experiment measures various stages of nuclear collisions utilizing the different types of beams from the Large Hadron Collider (LHC). PbPb collisions can provide remarkable insight into the final state effects, such as jet quenching. However, recent studies of pPb collisions shed light on initial state effects and complement a chronological picture of the nuclear interaction. CMS results of jet and hadron measurements in such collisions are presented.

Keywords:

1. Introduction

In studies of nuclear collisions at high energies at the LHC, evidence is seen for a strongly interacting quark-gluon plasma. Jets produced from high transverse momentum (p_T) partons produced in hard scatterings lose energy from transversing this hot, dense medium as predicted in [1]. Inclusive jets, b-jets, and charged hadrons are used by CMS to study the energy loss in the medium [2, 3, 4]. Analysis is performed on PbPb collisions and pp collisions, both at $\sqrt{s_{NN}} = 2.76$ TeV. There is clear evidence of jet quenching in central PbPb collisions in comparison to the pp collisions. In contrast, collisions of pPb are not expected to produce the quark-gluon plasma and provide indication of initial state nuclear effects. CMS results for pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV include charged hadrons, fully reconstructed jets, and b-jets [5, 6, 7]. In the pPb case, pp collisions do not exist at $\sqrt{s_{NN}} = 5.02$ TeV, thus simulations and extrapolations from other collision energies are used.

The nuclear modification factor (R_{AA}) is calculated as follows:

$$R_{AA} = \frac{d^2N^{AA}/dp_T d\eta}{\langle N_{coll}\rangle\, d^2N^{pp}/dp_T d\eta} = \frac{d^2N^{AA}/dp_T d\eta}{\langle T_{AA}\rangle\, d^2\sigma^{pp}/dp_T d\eta},$$

where $\langle N_{coll}\rangle$ is the average number of nucleon-nucleon collisions in heavy-ion (AA) interactions and $\langle T_{AA}\rangle$ is the nuclear overlap function. $\langle N_{coll}\rangle$ is equal to $\langle T_{AA}\rangle \times \sigma^{NN}_{inel}$, and is calculated with a Glauber model [8]. In essence the R_{AA} compares how many jets (or hadrons) are measured in PbPb (or pPb) as a ratio to the expectation of the average number of pp collisions superimposed.

2. PbPb analysis

In PbPb and pp collisions, jets are reconstructed with the anti-k$_T$ algorithm [9] utilizing information from the CMS particle-flow algorithm [10]. The particle-flow algorithm attempts to identify all stable particles in an event by combining information from the tracker with corresponding electromagnetic and hadronic calorimeter energies. The anti-k$_T$ algorithm is used with a resolution parameter R=0.3. In PbPb inclusive and b-jet studies, the underlying event is removed with the "iterative-pileup" subtraction technique [11]. Jets from b-quarks are identified through secondary vertex reconstruction. Both the inclusive and b-jet spectra are unfolded utilizing Bayesian unfolding as implemented by RooUnfold [12, 13].

The inclusive jet nuclear modification factor is studied for different centralities in a p_T range of

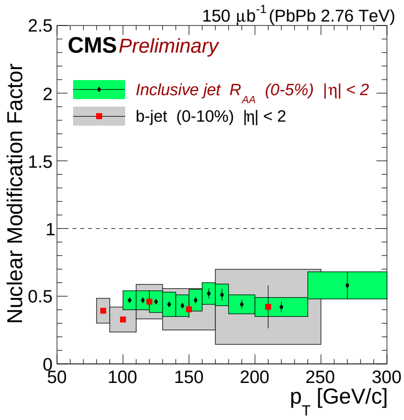

Figure 1: Inclusive jet (diamonds) and b-jet (closed boxes) nuclear modification factor measured in central PbPb collisions. Statistical uncertainty is represented by bars and systematic uncertainty by boxes.

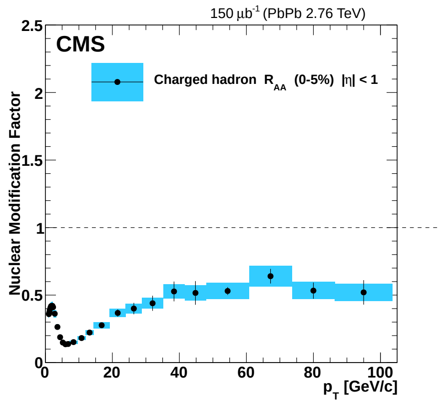

Figure 2: Charged hadron nuclear modification factor measured in central PbPb collisions for $|\eta| < 1$. Statistical uncertainty is represented by bars and systematic uncertainty by boxes.

100 to 300 GeV/c, and is found to decrease from peripheral to central collisions. The b-jets have similar behavior, with jets between 80 and 110 GeV/c having a decrease in the jet R_{AA} from peripheral to central events. Figure 1 shows the comparison of the inclusive and b-jet R_{AA} in the most central collisions. The statistical uncertainty is represented by bars and systematic uncertainty by boxes. An additional overall luminosity uncertainty of 4% is not shown. Inclusive and b-jets have the same suppression in central PbPb collisions in comparison to the pp collisions at 2.76 TeV.

Charged hadrons are identified with tracks measured in minimum bias PbPb collisions recorded in 2010. The hadron p_{T} reach is extended with the inclusion of jet triggered samples from 2011, with events that contain single jets of energy thresholds above 65 and 80 GeV/c. In the most peripheral events, the R_{AA} has a moderate suppression (∼0.6). As the centrality increases, the suppression at high p_{T} increases and is somewhat flat above 40 GeV/c. The most central charged hadron R_{AA} is shown in Fig. 2. The charged hadron R_{AA} reaches a minimum of about 0.13 between 5 and 10 GeV/c, and rises at higher p_{T}. For the high p_{T} region of charged hadrons (50 GeV/c and above), the charged hadrons and jets have a similar value of ≈ 0.5 for the nuclear modification factor which can be seen in comparison of Figs. 1 and 2.

3. pPb analysis

Data for pPb collisions were recorded in 2013 at 5.02 TeV center-of-mass energy. For pPb analyses, no centrality classification is implemented. Similar to PbPb, jets are reconstructed with the anti-k_{T} algorithm, R=0.3, and iterative pileup subtraction to remove any underlying event. Bayesian unfolding is implemented to correct for detector resolution effects on the jet spectra. The inclusive jet analysis is performed on minimum bias and jet triggered datasets. As there is no pp data at 5.02 TeV, the reference used in the jet R_{pA} is extrapolated based on CMS jet measurements at 7 TeV (for R=0.5, 0.7), as well as PYTHIA and NLO calculations. The inclusive jet R_{pA} is shown in comparison with the central PbPb R_{AA} in Fig. 3. The jet R_{pA} is near or at one within the uncertainties. This clearly indicates that the significant PbPb jet quenching is not due to initial state conditions.

The analysis of b-jets in pPb is performed in a similar fashion to that in PbPb, utilizing jet triggered datasets, but with no centrality classification. Secondary vertex reconstruction of charged tracks associated with jets is used to identify b hadrons and/or c decays. The b-jet reference was PYTHIA simulations produced for 5.02 TeV center-of-mass energy. Figure 4 has the b-jet R_{pA} compared to the central PbPb b-jet R_{AA}. It can be seen that the pPb results for inclusive and b-jets are comparable and near or at one within uncertainties. The b-jet suppression is also not due to initial state conditions.

Charged hadrons in pPb are measured utilizing both minimum bias and high p_{T} track triggered datasets. As

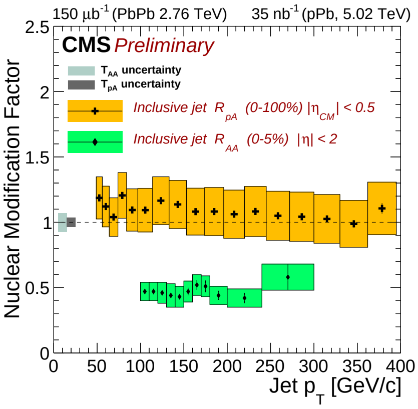

Figure 3: Inclusive jet R_{AA} (diamonds) and R_{pA} (plus symbols). The R_{AA} is measured in central collisions, and R_{pA} has no centrality classification. Statistical uncertainty is represented by bars and systematic uncertainty by boxes. The luminosity uncertainty for each system is represented by boxes at p_T near 0.

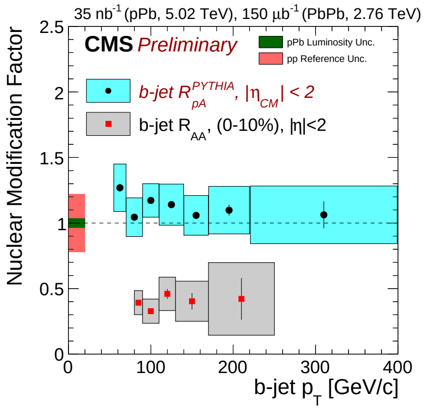

Figure 4: b-jet R_{AA} (boxes) and R_{pA} (closed circles). The R_{AA} is measured in central collisions, and R_{pA} has no centrality classification. Statistical uncertainty is represented by bars and systematic uncertainty by boxes. The luminosity uncertainty for each system is represented by boxes at $p_T = 0$.

pPb is an asymmetric collision system, the selection was made in the lab frame ($|\eta_{lab}| < 2.4$), where at the center of mass $\eta = 0$, the $\eta_{lab} = 0.465$. The pp reference is interpolated from charged hadron measurements from CMS pp collisions at $\sqrt{s} = 0.9, 2.76$, and 7 TeV, as well as CDF measurements from p$\bar{\text{p}}$ at 0.63, 1.8, and 1.96 TeV. The charged hadron results from pPb are compared to central PbPb in Fig. 5. At low p_T (2-5 GeV/c), the R_{pA} is 1 within uncertainty. There is a rise in the charged hadron R_{pA} at high p_T, but it must be considered that the pp reference used is extrapolated. For the charged hadrons, the suppression observed in high R_{pA} in central PbPb collisions is not due to initial state effects.

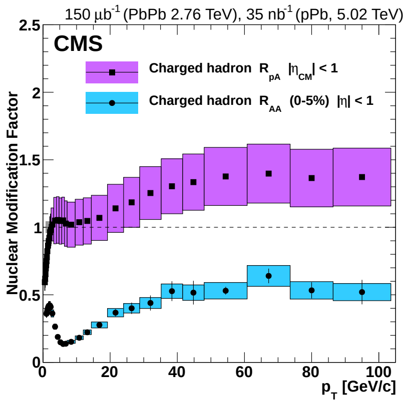

Figure 5: Charged hadron R_{AA} (closed circles) and R_{pA} (closed boxes). The R_{AA} is measured in central collisions, and R_{pA} has no centrality classification. Statistical uncertainty is represented by bars and systematic uncertainty by boxes.

4. Summary

Inclusive and b-jets were measured in PbPb and pPb collisions. Jets in central PbPb collisions, both inclusive and b-jets are suppressed at high p_T, showing the same level of suppression in the R_{AA}. Charged hadron measurements at high p_T show the same behavior as the jets in the central PbPb collisions.

In pPb compared to pp, inclusive and b-jets show no observed enhancement. The charged hadron R_{pA} has some rise at high p_T. There is a strong need for a measured reference to lower the uncertainties. Studies of pPb collisions indicate that the suppression observed in PbPb is not due to initial state effects.

5. Acknowledgement

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