The Compact Muon Solenoid Experiment
Conference Report

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Charged particle nuclear modification factor in PbPb at 5.02 TeV with CMS

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Abstract

In the high-luminosity 5.02 TeV collision-energy per nucleon pair PbPb and pp data provided by LHC in 2015, CMS measured the nuclear modification factor of charged particles from a transverse momentum of 0.7 GeV/c to 400 GeV/c in the central rapidity region. The centrality dependence of the nuclear modification factor is explored in several bins of collision centrality, from the most central 0-5pct to the peripheral 50-70pct centrality range. Comparisons of the measured nuclear modification factor of charged particles at 5.02 TeV are made to theory calculations and to measurements at lower collision energies. The nuclear modification factors are also compared to the measurements at 2.76 TeV with charged particles and fully reconstructed jets.

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In the high-luminosity 5.02 TeV collision-energy per nucleon pair PbPb and pp data provided by LHC in 2015, CMS measured the nuclear modification factor of charged particles from a transverse momentum of 0.7 GeV/c to 400 GeV/c in the central rapidity region. The centrality dependence of the nuclear modification factor is explored in several bins of collision centrality, from the most central 0–5% to the peripheral 50–70% centrality range. Comparisons of the measured nuclear modification factor of charged particles at 5.02 TeV are made to theory calculations and to measurements at lower collision energies. The nuclear modification factors are also compared to the measurements at 2.76 TeV with charged particles and fully reconstructed jets.

Keywords: nuclear modification factor, RAA, charged particle, 5.02 TeV, heavy ion collision

1. Introduction

The transverse momentum (p_T) spectra of charged particles produced in nucleus-nucleus (AA) collisions is sensitive to effects originating from the presence of a hot QCD medium known as the quark-gluon-plasma (QGP). In particular, the magnitude of the energy loss a parton experiences as it traverses this medium is imprinted on the final charged-particle spectrum as a large suppression as compared to a proton-proton collision reference which has been appropriately scaled to account for the larger number of colliding nucleons, $\langle N_{coll} \rangle$, in AA collisions [1]. In order to quantify this suppression, the nuclear modification factor, defined as

$$R_{AA}(p_T) = \frac{dN^{AA}/dp_T}{\langle N_{coll} \rangle dN^{pp}/dp_T}$$

is used. Here N^{AA} is the charged-particle yield in AA collisions, and N^{pp} is the yield of charged-particle production in pp collisions.

Measurements at RHIC observed a nuclear modification factor which is suppressed by a factor of 5, showing that the medium strongly influenced particle production [2, 3, 4, 5]. LHC data extended the p_T reach of these measurements from 25 GeV to 100 GeV at a center of

mass energy of 2.76 TeV. In these data, a maximum suppression of about 7 was observed [6, 7, 8].

The CMS collaboration recently recorded a data set of PbPb collisions at a center-of-mass energy per nucleon pair of $\sqrt{s_{NN}} = 5.02$ TeV having a total integrated luminosity of $404 \mu b^{-1}$. Additionally, a pp reference data set of $27.9 pb^{-1}$ was collected at the same energy. These large data sets allow the study of the nuclear modification factor at a center of mass energy that is roughly 2 times larger than previous studies [6], and up to unprecedentedly large charged-particle p_T . The measurement is also done for different ranges of overlap between the colliding nuclei, known as the collision centrality.

2. Procedure

The spectra used to construct R_{AA} were created by combining minimum bias data with jet-triggered data in both pp and PbPb collisions after calculating the appropriate normalization for each trigger pathway. The ratios of each trigger with the next lowest trigger after normalization is shown in Fig. 1. The lines converging to unity indicate that the normalization factors are calculated correctly. For the transverse momentum

Figure 1: The ratios of the leading offline jet p_T for each trigger pathway used in this analysis, after applying a normalization factor. The ratios converge to unity after the trigger combination. Lines have been added to guide the eye.

spectra, charged particles in the pseudorapidity range $|\eta| < 1$ are weighted by the corresponding trigger normalization. The contribution of each trigger to the total uncorrected track spectrum in the 0–5% centrality range is shown in Fig. 2. At low track p_T the minimum bias trigger dominates the trigger contribution, and as track p_T increases the contribution of various jet triggers increases. Each track has a correction applied to it, in order to account for tracking inefficiencies, acceptance and the misreconstruction of extra spurious tracks. An additional correction is applied to account for the uncertainty related to the fraction of strange baryons, which tend to be inefficiently reconstructed in the p_T range up to 10 GeV. This correction places the spectrum halfway between the spectra that would be reconstructed assuming the strange baryon fractions in data are equal to those of the PYTHIA 8 or EPOS LHC event generators. The PbPb spectrum is normalized by the number of minimum bias events used, while the pp spectrum is normalized by the total integrated luminosity and then scaled by the nuclear thickness function, $\langle T_{AA} \rangle$.

The largest uncertainties in this measurement are currently the uncertainty related to the strange baryon fraction (up to 16%), and the pp luminosity (12%). However, the pp luminosity uncertainty is expected to be greatly reduced upon further analysis of Van Der Meer scan data gathered during the 2015 run. Notably, the uncertainty related to the track p_T resolution is quite low (only 1.5%). Other uncertainties include differences between the tracking in data and MC (a 6.5% effect), and

Figure 2: The uncorrected track T spectrum for the 0–5% centrality range. The relative contribution of the 5 different triggers used in the analysis is shown by the stacked histograms. Because of the logarithmic scale, triggers on the top of each stack tend to contribute the most to the track spectrum at a given T .

uncertainties caused by the presence of non-negligible pileup in pp collisions (a 3% effect).

3. Results

The measured charged particle R_{AA} is shown in Fig. 3 and Fig. 4 for six centrality ranges. The blue and grey bands centers around unity represent the systematic uncertainties related to $\langle T_{AA} \rangle$ and the pp luminosity, respectively. The yellow bands represent the systematic uncertainties of the new measurement at 5.02 TeV, which the red boxes show the systematic uncertainties of the old CMS measurement at 2.76 TeV [6]. A strong suppression is seen around 8 GeV in the most central collisions. This suppression rises towards unity for p_T larger than this value. A modulation in the range of 0.7–5 GeV is seen, which characteristic of effects from radial flow [9], and Cronin enhancement [10]. As the collision centrality increases, R_{AA} flattens and becomes less suppressed. In all centrality ranges studied, the new measurement at a collision energy of 5.02 TeV is remarkably similar to the charged-particle R_{AA} measured at 2.76 TeV, as measured by ALICE, ATLAS, and CMS [7, 8, 6]. This could be due to a flattening of the particle spectra caused by the higher center of mass collision energy, which offsets effects which could cause greater suppression. The p_T reach of the new data is notable, probing the nuclear modification factor up to transverse momenta of 400 GeV.

Figure 3: The measured charged-particle R_{AA} at 5.02 TeV, compared to earlier measurements at 2.76 TeV from CMS [6], ALICE [7], and ATLAS [8] in centrality bins more central than 30%. The blue band around unity represents uncertainties related to N_{coll} , the grey band is the uncertainty on the pp integrated luminosity, and the yellow band represents all other systematic uncertainties.

Figure 4: The measured charged-particle R_{AA} at 5.02 TeV, compared to earlier measurements at 2.76 TeV from CMS [6] in centrality bins more peripheral than 30%. The blue band around unity represents uncertainties related to N_{coll} , the grey band is the uncertainty on the pp integrated luminosity, and the yellow band represents all other systematic uncertainties.

Figure 5: The charged-particle R_{AA} at 5.02 TeV, compared to two models of energy loss in the QGP. The red band the $SCET_G$ model [11], and the blue line is the CUJET 3.0 model [12].

Two models are compared to the measured R_{AA} in Fig. 5 for a central and mid-central selection of events. The first model, $SCET_G$, shown as a red band, combines initial state effects with a generalization of the DGLAP equations to include final state effects induced by the medium [11]. It reproduces the data well for the full range of the prediction. The second model, CUJET3.0, given by the dark blue line, is based on the Gyulassy-Levai-Vitev opacity series formalism [12]. It predicts a larger suppression than is seen in the data.

4. Conclusions

The charged-particle nuclear modification factor, R_{AA} , has been measured at $\sqrt{s_{NN}} = 5.02$ TeV in the p_T range of 0.7 GeV to 400 GeV by CMS. Improvement of the significant pp luminosity uncertainty is expected in the near future. A strong suppression is seen in central collisions, which is similar to suppression observed at lower collision energies by three LHC experiments. Less suppression and p_T -dependence is observed in peripheral collisions as compared to central collisions. The new data constrains in-medium energy loss models for high- p_T particles.

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