Pseudorapidity and centrality dependence of the transverse energy flow in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV from CMS

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Abstract

The measurement of the transverse energy density per unit of pseudorapidity $dE_T/d\eta$ over a broad range of pseudo-rapidities for PbPb collisions at the center-of-mass energy of 2.76 TeV per nucleon pair is presented. For the 2.5% most central collisions, $dE_T/d\eta$ at $\eta = 0$ was found to be 2.1 TeV. At all pseudo-rapidities the transverse energy per participating nucleon increases with the centrality of the collision. At $\eta = 0$, the transverse energy density grows faster with collision energy than the charged hadron multiplicity and faster than the logarithmic scaling used to describe lower energy data up to 200 GeV. Obtained results are compared to results from earlier experiments and with theoretical models.

1. Introduction

For extreme values of pressure, density, and temperature Quantum Chromodynamics predicts a phase transition from hadronic to deconfined matter [1]. It is believed, that such a deconfined matter existed in the Universe shortly after the Big Bang. Relativistic heavy-ion collisions allow to reach conditions necessary for the creation of the deconfined matter in the laboratory. The energy distribution of particles produced in the collisions is related to the initial energy and entropy densities of such a system. Measuring the transverse energy distribution over a wide pseudorapidity range can provide knowledge about the longitudinal evolution of the system. In addition, in this new energy regime, the initial state of the colliding nuclei may be a color glass condensate [2, 3, 4] and thus the spatial distribution of partons within the nucleus can be affected, particularly at high pseudorapidity [5, 6]. CMS [7] is a general-purpose experiment designed for the exploration of physics at the TeV energy scale. This detector is 22 m in length and 15 m in diameter featuring a 3.8 T solenoid surrounding central tracking detectors (silicon pixels and microstrips), as well as electromagnetic ($|\eta| < 3.0$) and hadronic ($|\eta| < 5.2$) calorimeters. Muon detectors ($|\eta| < 2.4$) are embedded in the flux return iron yoke of the magnet. CMS also has unique detection capabilities in the forward region thanks to CASTOR (-6.6 $< \eta < -5.2$) and ZDC ($|\eta| > 8.3$) calorimeters.

\textsuperscript{1}A list of members of the CMS Collaboration and acknowledgements can be found at the end of this issue.

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2. Measurement method

This analysis was performed with 0.3 \( \mu \text{b}^{-1} \) of the PbPb data collected at 2010. Minimum bias inelastic PbPb collisions were selected by requiring that either the Hadronic forward calorimeters, HF, or the Beam Scintillator Counters, BSC, detected a signal on both sides of the nominal interaction point. Further offline selections included: (1) the coincidence of three HF towers above a total energy of 3 GeV at each side of a reconstructed interaction point; (2) vertex reconstructed from at least two tracks within \( \pm 25 \text{ cm} \) of the nominal interaction point along the beam line and within a radius of 2 cm measured perpendicular to the beam relative to the average vertex position; (3) large-multiplicity beam-background events were rejected by requesting the compatibility of the observed pixel-cluster lengths with the hypothesis of a PbPb interaction at the estimated vertex; (4) events containing beam-halo muons were removed by a timing requirement on the BSC counters on opposite sides of the nominal interaction point. The event selection efficiency for hadronic PbPb interactions was estimated to be (97 \( \pm 3 \)% [8]. The measurement was performed in different centrality classes. The mean number of participating nucleons \( \langle N_{\text{part}} \rangle \) and its systematic uncertainty for each centrality class were estimated from a Glauber model of the nuclear collision [9, 10, 11]. To correct for the detector acceptance and inefficiencies correction factors were obtained from the HYDJET 1.8 [12] Monte Carlo event generator. The correction factor is \( \approx 1.6 \) for \( |\eta| < 2 \), decreases to \( \approx 1.1 \) by \( |\eta| = 4 \) and then increases to 2 at \( |\eta| \approx 5 \). The results were cross checked using data taken without magnetic field and in addition, for B = 3.8 T, data from tracks having \( p_T > 0.9 \text{ GeV/c} \) combined with the energies of the corresponding clusters in the calorimeters. The muons and neutrinos deposit negligible amount of energy in the calorimeters, thus they are excluded from this analysis and no correction factors are applied to account for them. Since calorimeters measure the energy deposited at various angles, the data are shown in terms of the distribution of energy in pseudorapidity, \( \eta \).

3. Results

Figure 1 (left) shows the \( |\eta| \) dependence of \( dE_T/\eta \) for different centrality ranges. The value of \( dE_T/\eta \) is \( 2.1 \pm 0.1 \text{ TeV} \) at \( \eta = 0 \) for the 0-2.5\% central collisions. For 0-2.5\% central collisions and \( |\eta| < 5.2 \) the shape of \( dE_T/\eta \) is consistent with a Gaussian with standard deviation \( \sigma_\eta = 3.4 \pm 0.1 \). The Gaussian and Landau descriptions in Fig. 1 are normalized to the CMS data at \( \eta = 0 \). The Landau-Carruthers [13, 14] and Landau-Wong [15] descriptions have distributions that are narrower than data. For central collisions, the HYDJET 1.8 describes well the data at small \( |\eta| \) but overestimates at large \( |\eta| \). The AMPT approach [16, 17] reproduces roughly the shape of \( dE_T/\eta \) but overestimates \( dE_T/\eta \) at full \( |\eta| \) region. Integrating \( (dE_T/(d\eta))/\langle N_{\text{part}} \rangle/2 \) over \( |\eta| < 5.2 \) and extrapolating to the full phase space gives a total transverse energy per pair of participating nucleons of 91 \( \pm 5 \) GeV for the most central events. Figure 1 (right) gives the dependence of \( (dE_T/(d\eta))/\langle N_{\text{part}} \rangle/2 \) on the \( \langle N_{\text{part}} \rangle \) for several \( |\eta| \) regions. At all \( |\eta| \) regions the transverse energy pseudorapidity density per participant pair increases with number of participants. The \( \langle N_{\text{part}} \rangle \) evolution of \( (dE_T/(d\eta))/\langle N_{\text{part}} \rangle/2 \) changes as a function of \( |\eta| \). The ratio of peripheral to central \( (dE_T/(d\eta))/\langle N_{\text{part}} \rangle/2 \) goes from 54 \( \pm 2 \)% at \( \eta = 0 \) to 68 \( \pm 2 \)% at \( |\eta| = 5.0 \). For \( \eta = 0 \) the HYDJET 1.8 describes well the centrality dependence of the transverse energy pseudorapidity density per participant pair.

Figure 2 shows the energy dependence of \( (dE_T/(d\eta))/\langle N_{\text{part}} \rangle/2 \) for central collisions at \( \eta = 0 \). For the top 5\% most central events it is measured to be 10.5 \( \pm 0.5 \text{ GeV} \). The \( \sqrt{s_{NN}} \) behavior of the transverse energy pseudorapidity density per participant pair can be described by
a logarithmic dependence up to $\sqrt{s_{NN}}=200$ GeV. At $\eta = 0$, $(dE_T/d\eta)/(\langle N_{\text{part}}\rangle/2)$ from 8.7 GeV to 2.76 TeV can be fit by a power-law dependence of the type $s_{NN}^n$ with $n \approx 0.2$. A similar tendency was observed in evolution of the charged particle multiplicity but $(dE_T/d\eta)/(\langle N_{\text{part}}\rangle/2)$ rises faster. For the 5% most central collisions CMS have measured $dE_T/d\eta = 2007 \pm 100$ GeV and $dN_{\text{ch}}/d\eta = 1612 \pm 55$ [11]. Dividing the measured transverse energy by the observed charged particle multiplicity for the same centrality gives a transverse energy per charged particle of 1.25 $\pm$ 0.08 GeV at $\sqrt{s_{NN}} = 2.76$ TeV. This compares to 0.88 $\pm$ 0.07 GeV at $\sqrt{s_{NN}} = 200$ GeV [18].

The following sources of systematic uncertainties were studied in this analysis: (1) energy scale of calorimeters; (2) the sensitivity of the result to the $z$ distribution of the vertex; (3) symmetry about $\eta = 0$; (4) auto-correlations in the measurement (HF is used both to calculate centrality and to measure $E_T$ for each centrality class); (5) calorimeter noise; (6) description of the dead areas of the HF detector in the MC and the centrality determination. For $|\eta| \leq 2.65$ [2.65 < $|\eta|$ < 5.2] the total systematic uncertainty is between 3.5-22 [10-17]% depending on the centrality of the collision. The statistical uncertainties are negligible.

The energy density per unit volume can be estimated from the Bjorken approach [19] using the energy density per unit rapidity. A widely used estimate of energy density is given by [18]:

$$\epsilon = \frac{1}{A c \tau_0} J(y, \eta) \frac{dE_T}{d\eta}.$$  \hspace{1cm} (1)

where $A$ is the overlap area of the two nuclei, $\tau_0$ is the formation time of the produced system and $J(y, \eta)$ is the Jacobian. For the top 5% most central collisions this formula gives $\epsilon = 14$ GeV/fm$^3$ at a time $\tau_0 = 1$ fm/c and for a transverse surface of $A = \pi \times (7 \text{ fm})^2$ [18]. This is by a factor 2.6 times larger than the energy density calculated at $\sqrt{s_{NN}} = 200$ GeV [18].
Figure 2: $dE_T/d\eta$ normalized by $(\langle N_{\text{part}} \rangle/2)$ for central collisions at $\eta = 0$ versus $\sqrt{s_{NN}}$. The data from 8.7 GeV to 2.76 TeV are fitted by a power-law dependence $0.46s_{NN}^{0.2}$. The vertical bar on the CMS point is the full systematic uncertainty. The solid line is a parametrization of lower-energy data compiled by the PHENIX Collaboration.

References