The Compact Muon Solenoid Experiment

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Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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Charged hadron multiplicity and transverse energy densities in PbPb collisions from CMS

Krisztian Krajczar on behalf of the CMS Collaboration

Abstract

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Krisztián Krajczár on behalf of the CMS Collaboration

MTA KFKI RMKI, Konkoly Thege Miklós út 29-33, 1121 Budapest, Hungary

E-mail: krisztian.krajczar@cern.ch

Abstract. Measurements of the charged hadron multiplicity and transverse energy are presented for minimum bias PbPb collisions at a centre-of-mass energy of 2.76 TeV per nucleon pair. The number of charged hadrons was obtained by two different methods based on the silicon pixel system of the CMS detector at the LHC. The two methods are in excellent agreement, resulting a charged hadron density of 1612 ± 55 for the 5% most central collisions. For the transverse energy measurement, CMS has almost hermetic calorimetry coverage with fine granularity and excellent resolution. In addition for particles near central rapidity momenta from the tracker can be combined with the calorimeter data to give a significant improvement of the system resolution. A transverse energy density of 2.1 TeV is observed for the most central 2.5% collisions. The measurements are compared with heavy-ion results from earlier experiments, where a smooth dependence on the collision energy and impact parameter is observed.

1. Introduction

Quantum Chromodynamics predicts a phase transition at high temperature between hadronic and deconfined matter [1]. Strongly interacting matter under such extreme conditions can be studied experimentally using ultra-relativistic collisions of heavy nuclei. The field entered a new era in November 2010 when the Large Hadron Collider at CERN produced the first PbPb collisions at a centre-of-mass energy per nucleon pair of $\sqrt{s_{\text{NN}}} = 2.76$ TeV. This represents an increase of more than one order of magnitude over the highest energy nuclear collisions previously achieved in the laboratory. The multiplicity and transverse energy densities of charged particles are key observables to characterise the initial properties of the matter created in these collisions.

The multiplicity of primary charged hadrons is measured by the pseudorapidity density, $dN_{\text{ch}}/d\eta$, where the pseudorapidity $\eta = -\ln[\tan(\theta/2)]$ and θ is the polar angle with respect to the beam line. Primary charged hadrons are defined as all charged hadrons produced, including the products of strong and electromagnetic decays, but excluding products of weak decays and hadrons originating from secondary interactions with the detector material. Transverse energy densities, $dE_{\text{T}}/d\eta$, are reported for all primary particles excluding neutrinos and muons.

A detailed description of the CMS experiment can be found in Ref. [2]. The detectors used for the measurements are the silicon tracking system covering the region $|\eta| < 2.5$, the Electromagnetic Calorimeter (ECAL), the Hadronic Calorimeter (HCAL) and the Hadronic Forward Cherenkov calorimeter (HF). ECAL and HCAL are physically divided into the barrel, $|\eta| < 1.4$, and endcap regions, $1.3 < |\eta| < 3.0$, while

HF covers $2.9 < |\eta| < 5.2$. The Beam Scintillator Counters (BSC, $3.23 < |\eta| < 4.65$) are used for event selection.

2. Measurement methods

The measurement of multiplicity [4] and transverse energy distributions [5] were performed using 100k and 2M minimum bias events recorded with 0 and 3.8 T magnetic field configuration of CMS, respectively. Minimum bias data were triggered by the logical OR of the coincidence signals of HF and BSC. Further offline selections included (among others) the coincidence of 3 HF towers above a total energy of 3 GeV at each side and a reconstructed interaction point. The simulation-based correction factors were determined using 100k events generated with the AMPT [6] and HYDJET [7] event generators using their default tunes subjected to reconstruction with the same version of software as used for the collision data.

The measurement of charged hadron densities is based on the high granularity pixel detector (66M channels) of the tracking system. The pixel tracker consists of three barrel layers (BPIX) and two end-cap disks at each barrel end, but only the barrel section was used in the measurement. The first BPIX layer is located at a distance between 3.6 and 5.2 cm from the beam line, the second one between 6.6 and 8.0 cm and the third layer between 9.4 and 10.8 cm. Two analysis methods were applied for the extraction of charged hadron densities. One only uses hits in single BPIX layers, and measures the hadron density based on the occupancy of the layer. The successful application of this method is the demonstration of the excellent pixel detector response and low occupancy even in the high-multiplicity PbPb environment. The other method uses doublets of hits reconstructed on pairs of BPIX layers, and can be regarded as the coincidence version of the first one. Using the angular coincidence of two hits from the same particle in different layers of the detector has the important feature of suppressing random noise. The results of the two methods differ by less than 1% and are averaged.

The transverse energy flow is measured based on the so-called particle flow objects [8] which combine calorimeter and full tracker information. As of now, the measurement is restricted to the η region covered by the barrel of ECAL and HCAL and by HF, $|\eta| < 1.3$ and $3.2 < |\eta| < 4.9$, where the systematics are well understood. The calorimeter cells are grouped in projective towers of granularity in pseudorapidity and azimuthal angle given by $\delta\eta\delta\phi = 0.087 \times 0.087$ at central rapidities. The segmentation becomes coarser at forward rapidities.

Nuclei are extended objects, and their collisions occur at various impact parameters, usually called “centralities”. Centrality is determined using the total sum of transverse energy in HF. The obtained centrality percentages are correlated with the total number of nucleons in the two Pb nuclei which experienced at least one collision, N_{part} , using the same Glauber model as Ref. [3].

3. Results

A primary charged hadron density of 1612 ± 55 at $\eta = 0$ is measured for the 5% most central collisions. The N_{part} -normalized hadron density, $(dN_{\text{ch}}/d\eta)/(N_{\text{part}}/2)$ is compared to various predictions in Fig. 1(a). The darker grey error band shows the systematic uncertainties affecting the scale of the measured distribution, while the light grey band shows all systematic errors. The two-component HIJING 2.0 model [9], which

Figure 1. (a) Measured $(dN_{ch}/d\eta)_{\eta=0}/(N_{part}/2)$ as a function of N_{part} in 2.76 TeV PbPb collisions. The model predictions are taken from [9], [10] and [13]. (b) Charged hadron pseudorapidity densities at $\eta = 0$ as a function of centre-of-mass energy for central 0–5% AA (top), 0–70% AA (middle) and inelastic pp (bottom) collisions fitted to power-law functions.

has been tuned to high-energy pp and central PbPb data can describe the general shape of the data. This model includes an impact parameter dependent gluon shadowing (s_g) parameter which limits the rise of particle production with centrality. The magnitude of the particle production favours a relatively large $s_g = 0.23$ parameter, although the shape of the centrality-dependence prefers a smaller $s_g = 0.17$. The observed centrality dependence is well reproduced by the saturation model of Albacete et al. [10]. Both [9] and [10] were published after ALICE reported the multiplicity of the 5% most central collisions [11], although previous saturation-based calculations (see e.g. [12]) predicted very similar central densities to those finally measured. The Regge-Gribov-theory-based DPMJET-III model [13] is capable of describing the charged hadron multiplicity in the most central collisions, but shows a stronger rise with centrality than observed in the data.

The collision energy dependence of $(dN_{ch}/d\eta)/(N_{part}/2)$ in the 5% and also in the 70% most central collisions can be seen in Fig. 1(b). The ALICE, PHOBOS, PHENIX and pp data are taken from [14], [15], [16] and [17], respectively. The error bars represent the total uncertainties. The normalized hadron density follows power-law dependence with exponents $s^{0.13}$ (PbPb) and $s^{0.09}$ (pp).

Figure 2(a) shows the η dependence of the transverse energy production. For the most central collisions ~ 2.1 TeV of transverse energy is created at $\eta = 0$, which is much larger than ~ 0.6 TeV measured at RHIC for $\sqrt{s_{NN}} = 200$ GeV. The systematic uncertainties are shown as an error band. The statistical errors are negligible. For central collisions, $dE_T/d\eta$ falls by a factor of two from $\eta = 0$ to $\eta \approx 4$. It is interesting to note that even at $\eta = 4.5$, $dE_T/d\eta$ and hence the energy density is higher than the one measured for $\eta = 0$ at RHIC.

Figure 2(b) shows the dependence on centre-of-mass energy per colliding nucleon pair of E_T production at central pseudorapidity. The lower energy data are from [16] and references therein. E_T rises more quickly with centre of mass energy than

Figure 2. (a) $dE_T/d\eta$ versus η distribution for the top 2.5% most central events. The coloured boxes show the systematic errors. (b) $dE_T/d\eta|_{\eta=0}$ divided by the number of participant pairs in the most central bin as a function of the centre-of-mass energy. The vertical bar on the CMS point is the full systematic error.

the logarithmic dependence used to describe data up to $\sqrt{s_{NN}} = 200$ GeV. From $\sqrt{s_{NN}} = 0.2$ to 2.76 TeV an increase of $(dE_T/d\eta)/(0.5N_{part})$ of 3.4 ± 0.4 compared to a factor of 2.2 ± 0.1 for multiplicity [4, 16] is observed. This difference could be attributed to the increase of the mean transverse momentum from RHIC to LHC.

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