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

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Measurement of Forward Energy Flow at 13 TeV with the CMS Experiment

Salim Cerci for the CMS Collaboration

Abstract

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Measurement of Forward Energy Flow at 13 TeV with the CMS Experiment

Salim Cerci^{1,a)}

¹*Adiyaman University, Faculty of Arts and Sciences, Department of Physics, 02040 Adiyaman, Turkey.*

^{a)}Corresponding author: salim.cerci@cern.ch
On behalf of the CMS Collaboration

Abstract.

The measurement of the energy flow is performed with the forward (HF: $3.15 < |\eta| < 5.2$) and very-forward (CASTOR: $-6.6 < \eta < -5.2$) calorimeters of CMS at the centre-of-mass energy of 13 TeV. The data were taken during the several periods of low luminosity operation in 2015. The results are compared to Monte Carlo (MC) model predictions as well as the earlier proton-proton data taken at $\sqrt{s} = 0.9$ TeV and 7 TeV. Furthermore, the beam fragmentation which provides valuable input for tuning of MC models used to describe high energy hadronic interactions is also studied at the regions close to the beam rapidities.

INTRODUCTION

The energy flow measurement is directly sensitive to the amount of initial state parton radiation and to multiple interactions. Multiple parton interactions (MPI) [1] phenomena can be probed by measuring in the centre-of-mass system the amount of energy created in inelastic hadron-hadron interactions at large values of the pseudorapidity (η). With the energy flow measurements the basic characteristics of the underlying event (UE) [2] and MPI as a function of pseudorapidity and center-of-mass energy can be explored. The energy flow previously has been measured with the lower centre-of-mass energies in $p\bar{p}$ [3], ep [4] and pp [5, 6, 7] collisions. The energy flow measurement presented in here is performed with minimum bias data which contains large contribution on non-perturbative interactions, and needs phenomenological models (hadronic interaction and cosmic ray) that can be tuned with energy flow measurements. It is a very good probe for testing diffractive production by using different event selections. Furthermore, it is possible to perform benchmark measurements of the energy flow due to the CMS experiment having a wide range of pseudorapidities ($\eta = -6.6$ to 5.2).

FORWARD CALORIMETERS: HF and CASTOR

The forward detectors in CMS are Cherenkov calorimeters. Quartz fiber used as a active material which was embedded within a steel absorber in Hadronic Forward (HF) calorimeter covering $2.9 < |\eta| < 5.2$. Photomultiplier tubes (PMTs) are used to detect the collected light in calorimetry. The CASTOR cover the very forward angles ($-6.6 < \eta < -5.2$) and are made of quartz plates embedded in tungsten absorbers. It has 16 azimuthal sectors and 14 longitudinal modules (2 modules in the electromagnetic section, 10 radiation lengths each and 12 modules in the hadronic section, twice the depth of electromagnetic modules each). The CASTOR calorimeter, made of stacks of tungsten/quartz plates readout with PMTs in two mechanical structures, is placed very close to the beam pipe at a distance of 14.4 m away from the interaction point. The overall longitudinal depth of each CASTOR and HF corresponds to 10 interaction lengths.

RESULTS

The measurement of the energy flow is performed with the HF and CASTOR calorimeters of CMS with 2015 early data at $\sqrt{s} = 13$ TeV [8]. In 2015, there were several run periods when special LHC beam conditions ensured relatively

low pile-up (PU). Two run periods, with PU of around 0.05 and 0.5, were found to be suitable to this analysis. The data acquisition in CMS was triggered by the presence of both beams in the interactions (Zero Bias triggers). In order to study the beam gas and other beam backgrounds as well as the influence of the detector noise samples with only one beam (“single beam” or “un-paired bunch”) or no beams present (“empty bunch”) were used. The energy flow is measured by summing up all energy deposits of the calorimeter towers above a noise threshold. Two different strategies are used for further offline selection of inelastic collision events: a *soft-inclusive-inelastic* (INEL) selection allowing significant fraction of diffractive events, a *non-single-diffractive-enhanced* (NSD-enhanced) selection where diffractive contributions are effectively suppressed. This is achieved by requiring activity in HF above some level either on at least one side (for the INEL events) or on both sides (for the NSD-enhanced events) with respect to the nominal interaction point of CMS. The selection of events at the particle level is defined as following. In the analysis of soft-inclusive-inelastic events, a cut $\xi \sim M_X^2/s > 10^{-6}$ is applied. This choice is motivated by considerations of compatibility with analysis of cross-sections of soft-inclusive-inelastic events where such a cut is applied in Ref. [9]. A motivation for the approach to the selection of non-single-diffractive-enhanced events is to compare with previously published CMS results at lower centre-of-mass energies. Hence the event selection is performed according to the CMS published results in Ref. [10].

The data are corrected to the particle level using the PYTHIA8 MONASH13 [11], PYTHIA8 4C with MBR [12], EPOS-LHC [13] and QGSJETII.4 [14] MC generators together with a simulation of the CMS detector based on GEANT4. For every pseudorapidity bin we combine the total detector level energy reconstructed using calorimeter towers with the final correction factor, taken as the average of the correction factors for four different MC samples, in order to get the particle level energy flow as a function of $|\eta|$. The particle level energy flow as a function of pseudorapidity, obtained using soft-inclusive-inelastic data at $B = 0$ T, is shown in Figure 1 compared to PYTHIA8 MONASH13, EPOS-LHC and QGSJETII.4 predictions. The gray band represents the total uncertainty, a quadratic sum for every bin (within a bin individual contributions to total systematics are not correlated), which is strongly dominated by the global calorimeter energy-scale uncertainties. The corrected data for soft-inclusive-inelastic are compared to the predictions of the PYTHIA8 MC event generator with the CMS tunes CUETP8M1 [15], CUET8M1+MBR and CUETP8S1 [15] in Figure 2 (left). The red band corresponds to the envelope of the uncertainties of the tune parameters of PYTHIA8 CUETP8S1 tune. The right panel of Figure 2 shows the ratio of measured data to MC predictions.

FIGURE 1. Left: A comparison of energy flow measurements as a function of η at $\sqrt{s} = 13$ TeV INEL events to MC models PYTHIA8 MONASH, EPOS-LHC and QGSJETII.4. The gray band shows the total systematic uncertainty correlated across pseudorapidity bins. Right: The ratio of measured data to MC predictions.

The left panel of Figure 3 shows a comparison of energy flow measurements as a function of pseudorapidity for non-single-diffractive-enhanced events to MC models at particle level defined with a requirement of at least two either charged or neutral particles in the range $3.15 < |\eta| < 5.20$, one on each side with respect to the interaction point. The right panel of Figure 3 shows the ratio of measured data to MC predictions. Similarly, the measured energy flow for non-single-diffractive-enhanced events is compared to the predictions of the PYTHIA8 MC event generator with the tunes CUETP8M1, CUETP8M1+MBR and CUETP8S1 in Figure 4 (left). The ratio of measured data for non-single-diffractive-enhanced events to PYTHIA8 MC event generator with the various tunes is shown in the right panel of Figure 4. The solid black line represents the ratio of results for non-single-diffractive-enhanced (NSD-enhanced) and

FIGURE 2. Left: A comparison of energy flow measurements as a function of η at $\sqrt{s} = 13$ TeV for INEL events to the predictions of the MC event generator PYTHIA8 with the tunes CUETP8M1, CUETP8M1+MBR and CUETP8S1. The red band corresponds to the envelope of the uncertainties of the tune parameters of PYTHIA8 CUETP8S1 tune. Right: The ratio of measured data to various PYTHIA8 tunes.

soft-inclusive-inelastic (INEL) events. In Figure 5 the measured transverse energy density, $dE_T/d\eta'$, is compared to the published CMS data at lower centre-of-mass energy and models as a function of shifted pseudorapidity variable, $\eta' = \eta - y_{beam}$, (y_{beam} stands for the beam rapidity) for non-single-diffractive-enhanced events selected with non-single-diffractive-enhanced / “BSC-AND” requirement.

FIGURE 3. A comparison of energy flow measurements as a function of η at $\sqrt{s} = 13$ TeV for NSD-enhanced events to MC models. Right: The ratio of measured data to MC predictions.

SUMMARY

A measurement of the energy flow in the forward rapidity region at $\sqrt{s} = 13$ TeV obtained with the CMS detector at the LHC is presented. The large spread observed on the different PYTHIA tunes show that the energy flow measurement in the forward rapidities is complementary to the central underlying event studies to tune the MC generators.

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FIGURE 4. Left: A comparison of energy flow measurements as a function of η at $\sqrt{s} = 13$ TeV for NSD-enhanced events to various PYTHIA8 tunes at particle level. Right: The ratio of measured data to various PYTHIA8 tunes and ratio of results for NSD-enhanced and INEL events shown as a solid black line.

FIGURE 5. Comparison of the measured particle level transverse energy density $dE_T/d\eta$ to the published CMS measurements and several models at different centre-of-mass energies as function of the shifted pseudorapidity variable, $\eta - y_{beam}$.

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