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Forward energy flow per pseudorapidity and limiting fragmentation with CMS at 13 TeV

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The measurement of the energy flow in the forward angular range performed by CMS at LHC is a means of studying soft particle production and testing hadronic interaction models used in collider as well as cosmic ray physics. The two important ingredients necessary for the measurement, forward instrumentation of CMS and the accelerator providing collisions with low pile-up, performed very well in 2015 at the start up of the operation at 13 TeV.

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1. Motivation

Soft particle production at 13 TeV awaits thorough studies. Any sings of new physics at the LHC are to be uncovered on top of a a large pile of several tens of overlapping soft interactions. Interpretation of high-p_{T} precision measurements of fundamental quantities, for example top quark mass, turns out to require good understanding of soft-inclusive particle production modelling.

Basic energy flow measurements provide useful input for tuning of existing hadronic interaction models. They serve also as an important reference for the extrapolation to the highest energies observed in the cosmic rays.

So far at LHC the energy flow has been measured by CMS [1] in pp collisions at 900 GeV and 7 TeV [2], in pPb collisions at 5.02 TeV [3] and PbPb collisions at 2.76 TeV [4] per nucleon. The results presented here [5] continue naturally along the same lines focusing on the forward psedorapidity range $3.15 < |\eta| < 6.6$ where most of the energy released in the collision can be observed.

2. Hadronic interaction models

Our results are compared to a set of PYTHIA8 [6] tunes and two models, EPOS-LHC [7] and QGSJET II.04 [8], extensively used in the cosmic ray physics. All Monte Carlo models considered are tuned to LHC Run1 data.

In the general purpose PYTHIA8 generator hard scattering matrix elements are supplemented by parton showering and string fragmentation in order to provide full collision event record. All aspects of the modelling process, in particular fragmentation, underlying event, diffractive processes, are highly tunable in PYTHIA8. The recent MONASH 2013 tune [9] explicitly aims at improved description of activity the forward angular range. The CMS tunes, CUETP8M1 and CUETP8S1, have been developed based on measurements of the underlying event [10].

The models commonly used in cosmic ray physics, EPOS-LHC and QGSJET II.04, implement the Gribov-Regge multiple scattering approach and use string fragmentation for hadronization. Collective effects are implemented in EPOS-LHC as a hydrodynamic component in a parametrized form. A set of tunable parameters available in EPOS-LHC makes it phenomenologically more flexible compared to theoretically rigour QGSJET II.04.

3. Event selection and measurement procedure

The low luminosity data taken by CMS at the start up of the LHC operation at 13 TeV are used in our analysis. We repeat the analysis for two distinct classes of collision events, the soft-inclusive-inelastic and non-single-diffractive-enhanced events, in several pseudorapidity bins. For soft-inclusive-inelastic events activity above a threshold is required in forward calorimeters on at least one side with respect to the nominal interaction point of CMS. In non-single-diffractive-enhanced events an activity above noise is present in forward calorimeters on both sides.

As a measure of the energy flow for every pseudorapidity bin the average of total sum of energies of all reconstructed calorimeter objects is taken. Only energies above a noise threshold

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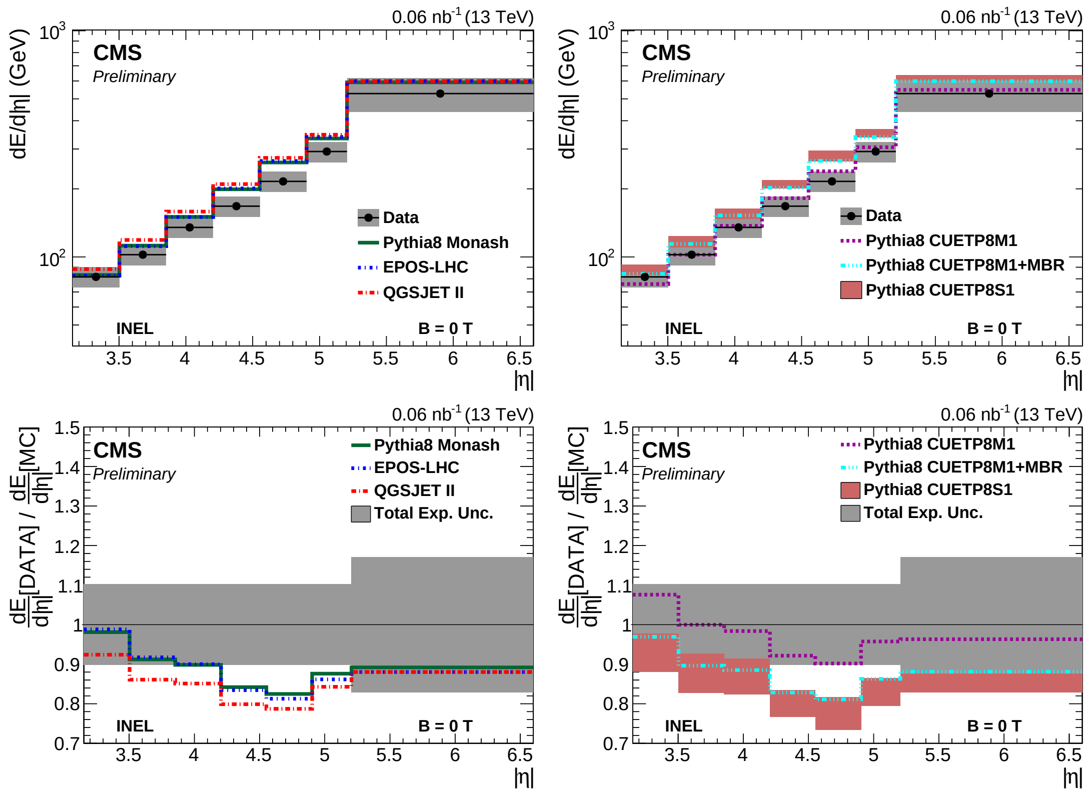

Figure 1: Comparison of corrected data for soft-inclusive-inelastic events to hadronic interaction models (in absolute values and as ratios), including several PYTHIA8 tunes with different approaches to modelling of diffraction (see [11]), EPOS-LHC and QGSJET II.04.

are considered. The noise level is estimated using data taken with either random trigger or triggers on non-colliding bunches. A small correction, factor ~ 1.025 is introduced to account for pile-up.

In order to facilitate comparison to model predictions we correct the energy flow measured in calorimeters to particle level using GEANT-based Monte Carlo detector simulation. For the energy sums at particle level only stable particles, hadrons and leptons excluding muons and neutrinos, are counted. The event selection at the particle level for the soft-inclusive-inelastic events is defined using kinematic variable $\xi = M_X^2/s$, the scaled mass of the largest (diffractively dissociated) system separated from the rest of the observed final state by the biggest rapidity gap. The scaled mass is required to be above 10^{-6}. For the non-single-diffractive-enhanced events presence of particles, charged or neutral, is required in the pseudorapidity range $3.15 < |\eta| < 5.20$. The requirement implies activity on each side with respect to the interaction point, that is both at positive and negative pseudorapidities. The global calorimeter energy scale uncertainties, 10% (20%) in the range $3.15 < |\eta| < 5.20$ ($5.20 < |\eta| < 6.6$), are the main factors contributing to the total uncertainties of the final results. The second biggest contribution comes from the model dependence of the particle level correction reaching 3.5%.

4. Results and discussions

The measurements of the energy flow at 13 TeV in the forward pseudorapidity region $3.15 <$

$|\eta| < 6.6$ of CMS are presented in Figs. 1–2. The measurement results are compared to PYTHIA8 tunes, EPOS-LHC and QGSJET II.04 hadronic interaction models. The overall description of the data by the predictions at the new energy scale reached by LHC is reasonable given uncertainties of the data, in particular the CMS underlying event tune CUETP8M1 (with nominal settings for modelling of diffraction) provides the best description of the data both for soft-inclusive-inelastic and non-single-diffractive-enhanced events. In Fig. 3 a comparison of the results at 13 TeV to previous measurements of the transverse energy flow at 900 GeV and 7 TeV in terms of pseudorapidity shifted by the beam rapidity, $\eta - y_{\text{beam}}$, is shown. Similar trends supporting the hypothesis of limiting fragmentation are visible in the data and in the hadronic interaction models confronted to the data.

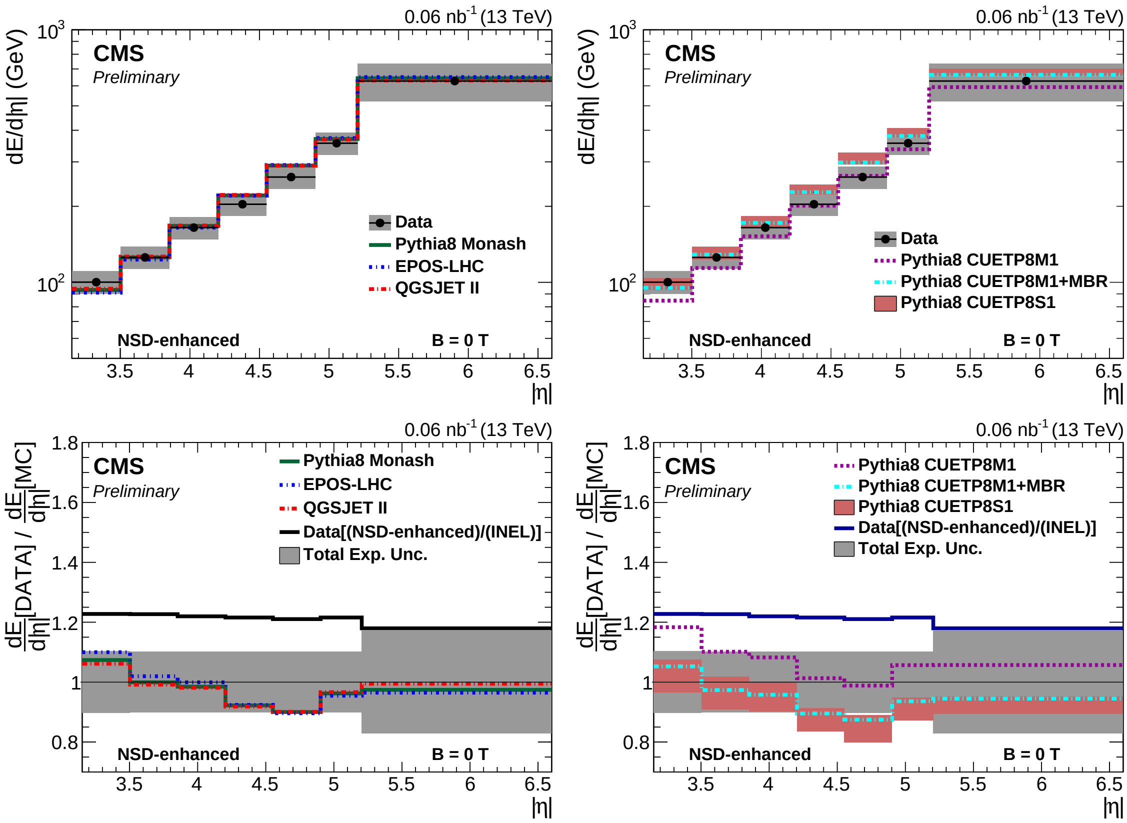

Figure 2: The same as Fig. 1 but for non-single-diffractive-enhanced events.

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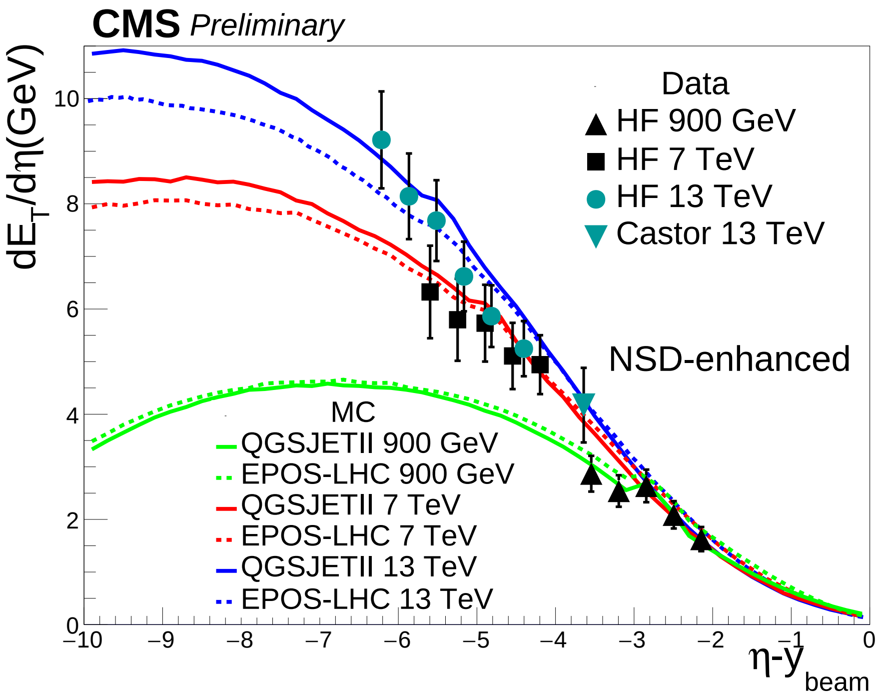

Figure 3: Comparison of corrected transverse energy flow to previous CMS measurements [2] and several models at different center-of-mass energies as function of shifted pseudorapidity variable. The particle level is defined according to the previous CMS measurements [2].

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