The Compact Muon Solenoid Experiment
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Measurements of forward energy flow with CMS

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Measurements of the forward energy flow in minimum bias events and in events with either hard jets or W and Z bosons produced at central rapidities are presented. Results are compared to MC models with different parameter tunes for the description of the underlying event.

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Abstract. Measurements of the forward energy flow in minimum bias events and in events with either hard jets or W and Z bosons produced at central rapidities are presented. Results are compared to MC models with different parameter tunes for the description of the underlying event.

1 Introduction and motivation

Quantum Chromodynamics processes can be investigated through the measurement of the average energy per event (energy flow) in specific angular regions. Such a measurement is useful in examining the complex final states that result from a hadron-hadron interaction. The LHC with its large centre-of-mass energy allows to study final states from the proton-proton interaction with large contributions from multiple-parton interactions (MPI). Multiple-parton interactions are not well understood theoretically and a systematic description in QCD remains challenging. Phenomenological approaches to multi-parton dynamics rely strongly on parameterised models and tuned parameters (tunes) to describe data. Measurements of the underlying event structure have been performed for central values of the pseudorapidity. The extension of the measurements to large pseudorapidities and higher centre-of-mass energies is a challenge for the models since, in this region of phase space, parton showers (initial-state radiation), as well as MPI, are expected to play a significant role. Exploiting the large calorimeter coverage of the Compact Muon Solenoid (CMS) detector [1] allows the energy flow to be measured over a wider range than was accessible in previous analyses. The measurement of the energy flow in the pseudorapidity range $3 < |\eta| < 5$ is presented at two different centre-of-mass energies, 0.9 and 7 TeV and for different event classes: minimum-bias events and events with central high-transverse-momenta dijets and events with a centrally produced W or Z boson.

2 Minimum-bias and dijet events

The energy flow was measured with the CMS hadronic forward (HF) calorimeters and corrected to the stable-particle level. A detailed description of the event selection can be found in [2]. The results for $\sqrt{s} = 7$ TeV are shown in Fig. 1. We observe three distinct features of the data. The first is that the energy flow in both minimum-bias and dijet events increases with pseudorapidity, and the increase is found to be steeper for minimum-bias events. The second is that the energy flow increases with centre-of-mass energy, being a factor of

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two to three higher at $\sqrt{s} = 7$ TeV than at $\sqrt{s} = 0.9$ TeV. Finally, the average energy flow is significantly higher in dijet events than in the minimum-bias sample. The data are compared to different MC predictions. The shape of the energy-flow distribution, both in minimum-bias and dijet events, is reproduced by all the MC event generators that include a contribution from MPI. The measured energy flow is also compared to predictions derived from the event generators used in cosmic-ray air shower simulations and the description of the data by all these models is good.

Figure 1: Energy flow as a function of η for minimum-bias and dijet events at $\sqrt{s} = 7$ TeV. The systematic uncertainties are indicated as error bars, the statistical errors are negligible. The yellow bands illustrate the spread of the predictions from the considered PYTHIA6 tunes.

3 W and Z boson events

The observables used to study the underlying event structure in W and Z events are the track multiplicity in the central detector, the energy depositions in both HF calorimeters and the correlations between them. A more detailed

Figure 2: The summed HF+ and HF- energy distributions in $W \rightarrow \mu\nu X$ candidate events for data and MC with different tunes for the underlying event. The band indicates the uncertainty related to a $\pm 10\%$ HF energy scale variation, the main systematic uncertainty.

description can be found in [3]. The results for the measured forward energy flow in the HF detectors are shown in Fig. 2. Besides the ProQ20 tune, none of the MC models considered provide a good description of the HF energy distribution observed in the data. The forward/backward correlations of the measured forward energy flow is highly sensitive to the underlying event. In Fig. 3 different energy intervals are shown and we observe a strong positive correlation between forward and backward energy deposits in data as well as in MC. The distributions for the medium energy interval are in better agreement with the predictions of the various tunes than the inclusive HF distributions, while for the low and high energy intervals it is worse.

Figure 3: The energy distribution in the HF+ calorimeter, shown for different HF- energy intervals for data and MC with different tunes for the underlying event.

4 Conclusions

The energy flow at large pseudorapidities has been measured in pp collisions for minimum-bias events and events with a dijet system or a W or Z boson in the central region. The results indicate the importance of the MPI in the description of the data with the MC models. The variation of the energy flow with η , both in minimum-bias and dijet events, is reasonably well reproduced by all Monte Carlo event generators with multiple-parton interactions included. However, in the W (Z) events larger discrepancies are observed and large efforts are needed especially for a simultaneous description of the forward/backward correlations. As can be seen by the large spread in the theoretical predictions, the magnitude of the average energy strongly depends on the parameter settings of the different MC tunes. Thus, the measured energy flow can be used for further constraints on the modeling of multiple-parton interactions.

References

- [1] CMS Collaboration, *JINST* **0803** (2008), S08004.
- [2] CMS Collaboration, arXiv:1110.0211 [hep-ex] (2011)
- [3] CMS Collaboration, arXiv:1110.0181 [hep-ex] (2011)