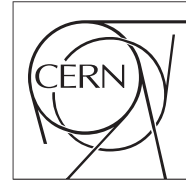


The Compact Muon Solenoid Experiment  
**Conference Report**

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# Multiple Parton Interactions, Underlying Event and Forward Physics at LHC

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## Abstract

A variety of physics measurements in the low and high  $P_T$  regimes will be performed by the LHC experiments in proton-proton collisions at  $\sqrt{S} = 14$  TeV to study the Multiple Parton Interactions (MPI) processes. The amount of activity in Minimum Bias and high  $P_T$  events will be quantified studying charged tracks and calorimetric clusters. The contribution of MPI to the Underlying Event (UE) will be studied by examining the production of charged particles in the region transverse to jets and in the central region of Drell-Yan muon pairs production. The effective double parton scattering cross section is expected to be measured in different topologies. The study of the activity in diffractive topologies will allow disentangling the MPI component of the Underlying Event from the Beam Remnant and Radiative components.

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# 1 Introduction

Evidence for Multiple Interaction phenomena is strongly supported by both the high- $P_T$  [AFS, CDF] and low- $P_T$  [CDF, UA5] [1] [2] [3] phenomenology at hadron colliders. Such processes have been implemented in the most popular QCD models since the '80 [4]. The deep understanding of the softer component of the collision recently achieved by the CDF collaboration allowed even more sophisticated implementations accounting for flavour and color correlations between different partonic interactions [5]. This paper is subdivided into three sections: in the first section will be discussed the Underlying Event universality and the measurement plan for LHC, the second section is dedicated to the interplay with the forward region and in the third section is briefly discussed the double parton scattering measurements foreseen at LHC.

## 2 The Underlying Event universality: the measurement plan for LHC

### 2.1 Underlying Event in the central region

One can use the topological structure of hadron-hadron collisions to study the UE by looking only at the outgoing charged particles [6]. Jets are constructed from the charged particles using a simple clustering algorithm and then the direction of the leading charged particle jet is used to isolate regions of  $\phi$  space that are sensitive to the UE. The transverse region to the charged particle jet direction is almost perpendicular to the plane of the hard, back to back, scattering and is therefore very sensitive to the UE (left Figure 1).

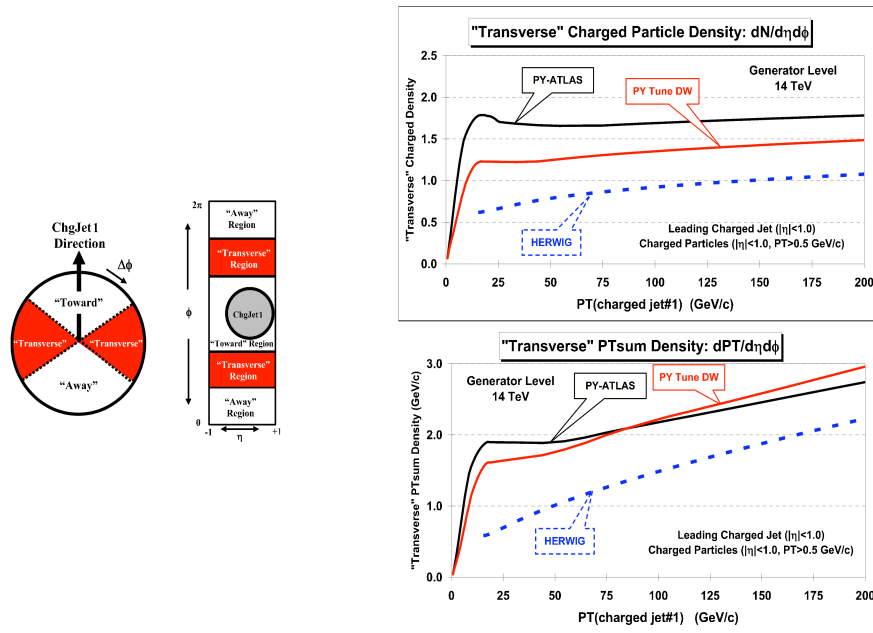


Figure 1: Left: sketch of the proton-proton interaction in the transverse plane. Right: QCD Monte Carlo models predictions for charged particle jet production at the LHC. Average density of charged particles,  $dN_{chg}/d\eta d\phi$ , with  $|\eta| < 1$  in the Transverse region versus the transverse momentum of the leading charged particle jet with two different cuts on the minimum  $p_T$  of the charged particle:  $p_T > 0.5$  (top) and  $p_T > 0.9$  (bottom)

The charged jet  $P_T$  ranging from 900 MeV/c (or 500 MeV/c depending on the lowest threshold for tracking) to 200 GeV/c shown in right figure 1 is quite interesting: due to the MPI, the PYTHIA tunes rise quickly and then reach an approximately flat plateau region at  $P_T \sim 20$  GeV/c. Then at  $P_T \sim 50$  GeV/c they begin to rise again due to initial and final state radiation which increases as the scale of the hard scattering. The two versions of PYTHIA, with Multiple Parton Interactions model, behave much differently than HERWIG without MPI.

The charged density distributions in jet topologies are studied by ATLAS and CMS with full simulation (Figures 2 and 3). In the ATLAS studies (Figure 2) the leading calorimetric jet is used as reference for the energy scale of the process and the investigated region is extended up to 1 TeV. Results are summarized in terms of the average number of reconstructed tracks in the transverse region and the  $p_T$  sum average of those tracks [7]. In the CMS studies (Figure 3) the energy scale is defined by the leading charged jet of the event and the observables in the transverse region are the average charged and energy density (left and right Figure 3). Reconstructed and simulated quantities

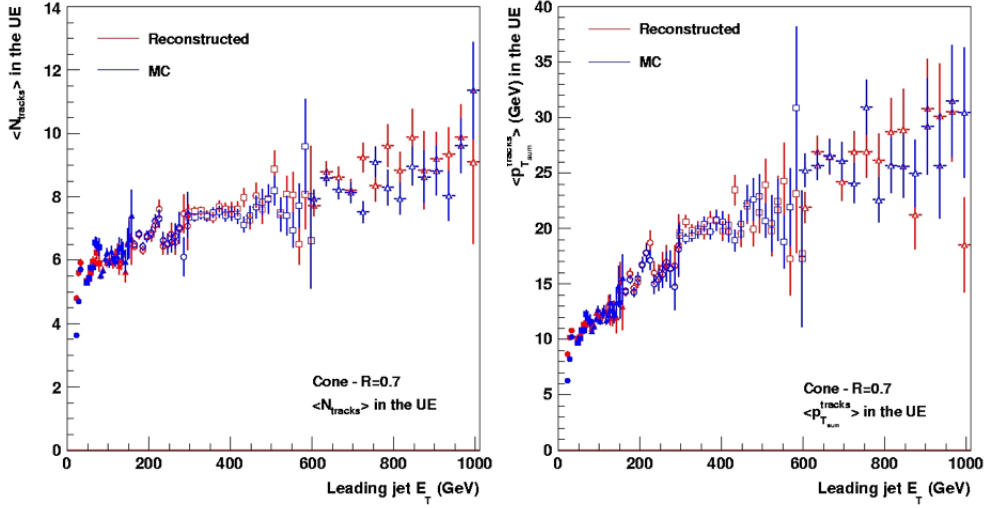


Figure 2: ATLAS. Mean number of tracks (left) and track  $p_T$  sum (right) in the transverse region for both reconstructed (red) and MC (blue) versus the transverse energy of the leading calorimetric jet.

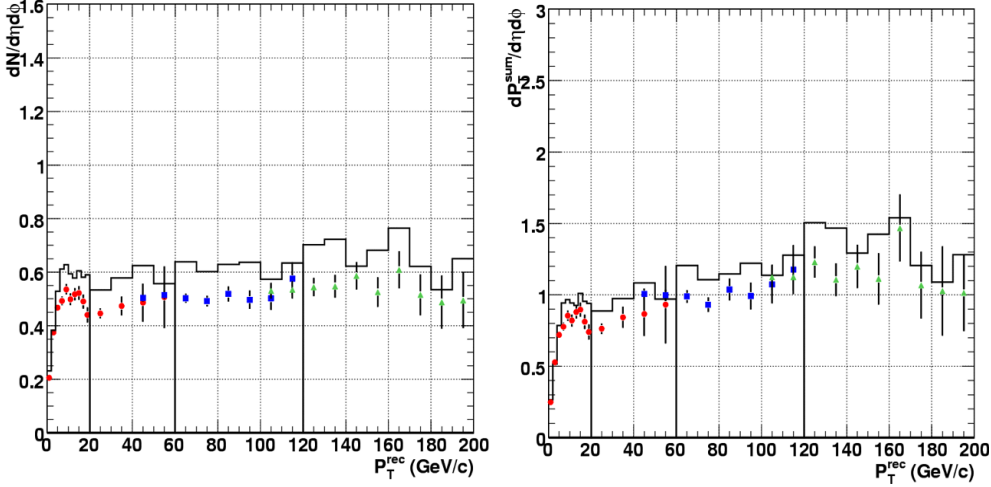


Figure 3: CMS. Density of charged particles,  $dN_{chg}/d\eta d\phi$  (left) and average charged  $p_T$  sum density,  $dP_T^{sum}/d\eta d\phi$  (right), with  $p_T > 0.9$  GeV/c and  $|\eta| < 1$  in the transverse region versus the transverse momentum of the leading charged particle jet.

agrees considering charged jet calibration [8] and the lower track reconstruction efficiency in the transverse region (where the spectrum is softer). The ability to lower down the  $p_T$  threshold for track reconstruction, allows to reach a higher discriminating power between different MC tunes (as shown in the right Figure 1) with a more inclusive measurement and a better control of the systematic errors related to efficiency, purity and  $p_T$  estimation. Both ATLAS and CMS experiments have developed several techniques to lower down as much as possible the  $p_T$  threshold, the most promising relies on tracking with the pixel detector [9]. Drell Yan muon pair production has been used by CMS to study the UE in an alternative and cleaner topology [8]. In these events the scale of the hard scattering is given by the muon pair invariant mass while all the other charged tracks are attributed to the UE. Figure 4 shows the prediction for the charged density and energy density in the whole  $\phi$  region.

## 2.2 Underlying Event in the forward region

In diffractive events at least one of the colliding protons survives in the final state. The beam remnant contribution is then reduced and also MPI are reduced. These topologies are studied exploiting the forward region of the detector.

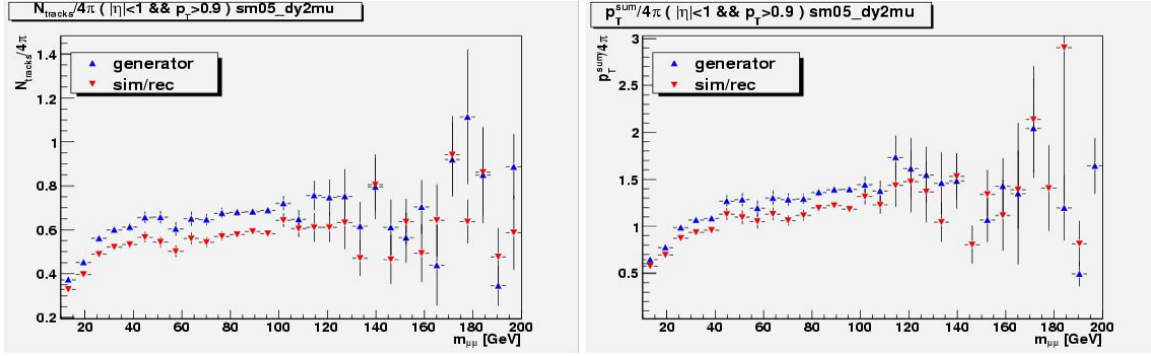


Figure 4: CMS. Density of charged particles,  $dN_{chg}/d\eta d\phi$  and average charged  $p_T$  sum density,  $p_T^{sum}/d\eta d\phi$  (right), with  $p_T > 0.9$  GeV/c and  $|\eta| < 1$  versus the muon-pair invariant mass. Blue triangles are referred to generator-level quantity while the red ones to the full simulated and reconstructed.

Hard diffractive events, such as  $pp \rightarrow p + X + Jet$  are used to study the underlying event activity in a similar way as in not-diffractive topology (eg:  $pp \rightarrow X + Jet$ ), in example using the jet to define the energy scale and studying the UE activity in the transverse region. A comparison between the diffractive and not diffractive processes helps to disentangle the different UE components.

The CMS collaboration is pursuing a program on forward and diffractive physics also with the CASTOR [10] forward cherenkov calorimeter and the near-beam detectors at  $\pm 220$  m from the interaction point (IP) that are part of the TOTEM experiment [11]. The goal is to carry out this program as part of the routine CMS data taking with nominal LHC optics and up to the highest luminosities.

Triggering on the forward and very forward regions, using the CMS Hadron Forward (HF) and CASTOR calorimeters, may give rise to biases depending on the UE model.

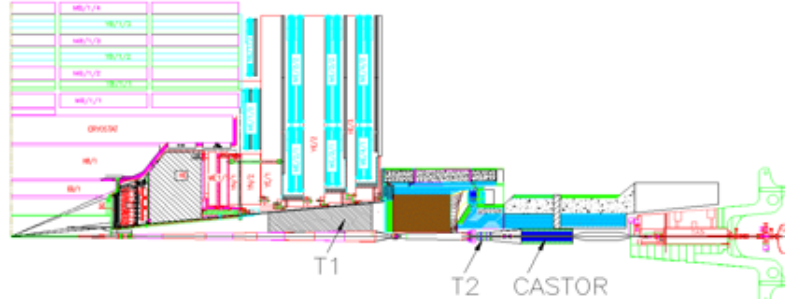


Figure 5: Sketch in the z-y plane of the TOTEM telescopes (T1 and T2). It is also indicated the CASTOR calorimeter.

The forward CASTOR detector covers the region  $5.32 < |\eta| < 6.86$  and permits to investigate the forward activity using central/forward correlations at large rapidity range taking into account the effect of the long-range correlation for model with MPI. It is possible with an ad hoc forward trigger, to enhance the discriminative power in the central region. Figure 6 shows that a little difference in multiplicity in the central region for realistic models as Tune A (itune=303) [12] and new showering model (itune=304) [13] is enhanced in the forward region. For example, depending on the parameterization used for MPI model, more or less energy is taken from the beam remnant as shown in right Figure 7.

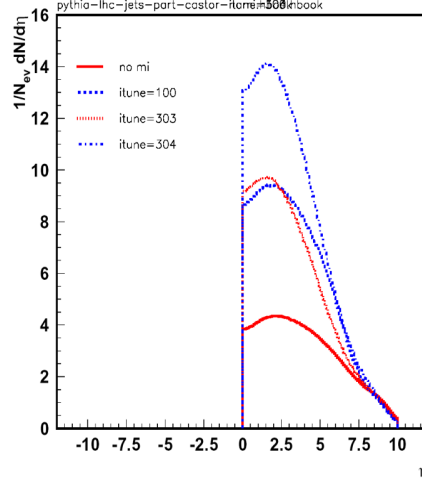


Figure 6: Charged particles multiplicity: different activity in the central region corresponding to different MC model (itune = 303 and 304) could be enhanced triggering with CASTOR in the forward region.

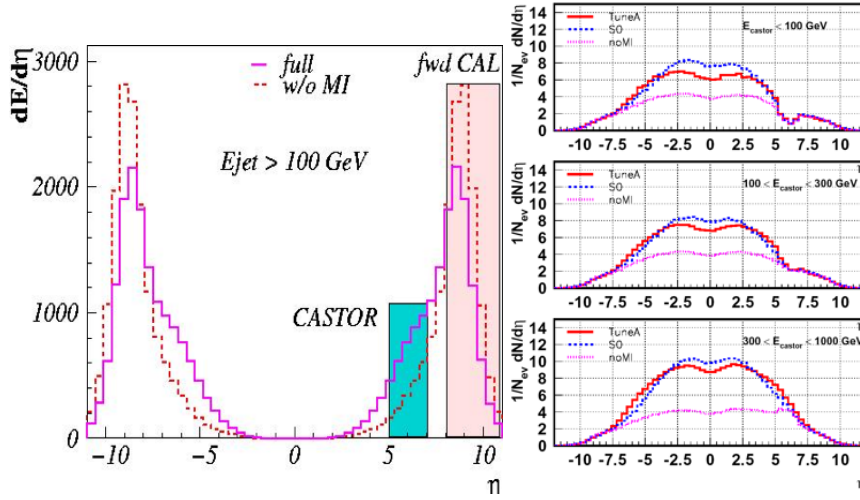


Figure 7: The energy flow measured by CASTOR (left plot) will help to model the beam remnants contribution and long range correlations (right plot) measuring the central/forward activity using different CASTOR trigger thresholds.

### 3 MPI in High-PT

The final goal is to achieve a uniform and coherent description of multiple parton processes in both High and Low- $P_T$  case. To quantify the High- $P_T$  contribution CMS proposes a program based on double parton scattering [14][15]. In the simplest model a double high- $P_T$  scattering can be interpreted as 2 different independent hard scatters superimposed. The corresponding cross section is parameterized as:

$$\sigma_{DP} = m \frac{\sigma_A \sigma_B}{2\sigma_{eff}}, \text{ where } \sigma_{eff} = \left( \frac{N_{DI}}{N_{DP}} \right) \left( \frac{N_c(1)}{2N_c(2)} \right) \sigma_{NSD}$$

where A and B are 2 different hard scatters,  $m=1,2$  for indistinguishable or distinguishable scattering and  $\sigma_{eff}$  contains the information about the spatial distribution of the partons. In this formalism  $\sigma_B/2\sigma_{eff}$  is the probability that an hard scatter B occurs given a process A and this will be larger or smaller depending on the parton spatial density. The CMS experiment foresees to accomplish this kind of studies using (as CDF [16]) 3jet+ $\gamma$  topology, same sign W production (that is greatly enhanced at the LHC energies as shown in figure 8) and minijet pairs production [17].

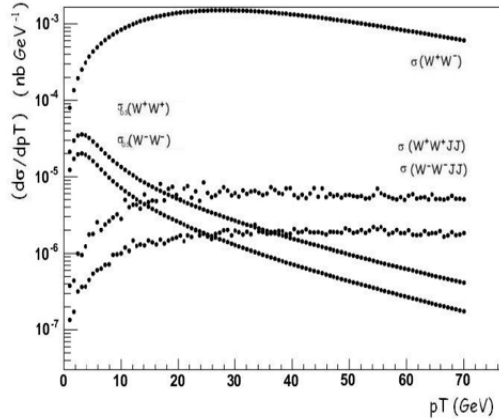


Figure 8: differential cross section for the same sign W production. Contribution from double parton interaction are superimposed to the single parton interaction production.  $W^+W^-$  cross section is also drawn as reference.

## 4 Conclusions

MPI can be studied using several processes:

- In the central region, studies are advanced for both CMS and ATLAS experiment using Jets and Drell-Yan topologies
- The possibility to use the forward region seems to be in a most advanced state for CMS and TOTEM experiments than for the ATLAS one, studies are ongoing exploiting the possibility to combine different detectors (TOTEM/CMS) and using a dedicated forward subdetector (CASTOR)
- Studies are also ongoing exploring the possibility to measure the double parton scattering, finalized to provide a description of the High- $P_T$  multiple parton interaction

Final goal for LHC will be to identify as best as possible observables and regions where the sensitivity to UE, and in particular the MPI contribution, is maximized. In this way, LHC experiments can be able to properly calculate and understand the underlying event contribution to the measurement and go back to the parton level with an uncertainty as small as possible. The UE, finally, will be process dependent and needs a careful modelling. In particular, for what concern the MPI, its contribution to the measured cross section has to be carefully understood, again a good modeling is needed to be able to subtract the contribution with only a small uncertainty.

## 5 Acknowledgments

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